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**Project Report No. 576**

***Assessing Iron-Enhanced Swales for  
Pollution Prevention***

Final Report

By

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## Table of Contents

<b>TABLE OF CONTENTS .....</b>	<b>II</b>
<b>LIST OF FIGURES .....</b>	<b>IV</b>
<b>LIST OF TABLES .....</b>	<b>VI</b>
<b>PROJECT SUMMARY.....</b>	<b>1</b>
<b>I. WORK PLAN REVIEW.....</b>	<b>4</b>
<b>II. GRANT RESULTS.....</b>	<b>7</b>
<b>1. Introduction .....</b>	<b>7</b>
<b>2. Design and Development of Iron-Enhanced Ditch Checks for Roadside Swales/Ditches</b>	<b>9</b>
2a. Background: Iron-Enhanced Ditch Check Prototype.....	9
2b. Full-Scale Design Components .....	9
<b>3. Iron-Enhanced Ditch Checks for MnDOT Swales .....</b>	<b>20</b>
3a. Site Description .....	20
3b. Design and Construction of Ditch Checks at MnDOT Swales .....	22
3c. Methods and Measurements.....	24
3d. Results of Field Testing Using Synthetic Runoff.....	30
3e. Results of Field Monitoring During Rainfall Events .....	31
<b>4. Iron-Enhanced Ditch Checks for City of Roseville Swales.....</b>	<b>43</b>
4a. Site Description .....	43
4b. Design and Installation of Roseville Ditch Check .....	45
4c. Field Testing Method .....	46
4d. Results of Field Testing.....	48
<b>5. Example Application .....</b>	<b>52</b>
<b>6. Summary and Conclusions .....</b>	<b>52</b>
<b>7. Products .....</b>	<b>54</b>
<b>8. Public Outreach and Education .....</b>	<b>55</b>
<b>9. Long-term Results .....</b>	<b>55</b>
9a. Lessons Learned and Recommendations .....	55
9b. Partnerships and Alliances .....	56
9c. Dissemination of Project Results .....	57
<b>III. FINAL EXPENDITURES .....</b>	<b>57</b>

<b>REFERENCES.....</b>	<b>58</b>
<b>APPENDIX A.....</b>	<b>60</b>
<b>1. Design and Construction of Iron-Enhanced Ditch Checks in MnDOT Swales, TH5, Stillwater.....</b>	<b>60</b>
1a. Material Specifications.....	60
1b. Ditch Check Design Plans.....	61
1c. Description of Iron-Enhanced Ditch Check Construction at MnDOT Swales (Sites 1 and 2) .....	65
<b>2. Design and Construction of Iron-Enhanced Ditch Checks in City of Roseville Swales.....</b>	<b>74</b>
2a. Material Specifications.....	74
2b. Description of Ditch Check Construction at Roseville Swales.....	76
<b>APPENDIX B.....</b>	<b>81</b>
<b>Typical Design Recommendations for Iron-enhanced Swale Ditch Checks .....</b>	<b>81</b>
<b>APPENDIX C.....</b>	<b>83</b>
<b>Grant Project Summary.....</b>	<b>83</b>
<b>Executive Summary of Project .....</b>	<b>84</b>
<b>APPENDIX D.....</b>	<b>87</b>
<b>1. Field Testing Data Summary for Roseville Swale Ditch Check .....</b>	<b>87</b>
<b>2. Field Monitoring Data Summary for MnDOT Swale Ditch Checks .....</b>	<b>87</b>

## List of Figures

Figure 1. Particle size distribution and photographs of the sand and iron shavings samples tested for application as filter media in the iron-enhanced ditch check.....	11
Figure 2. Constant-head permeability test setup used for measuring the saturated hydraulic conductivities of sand samples.....	12
Figure 3. Schematic of the profile and sectional views of the hypothetical iron-enhanced ditch check design used for the drain time modeling exercise. Design parameters of the ditch check are tabulated. ....	13
Figure 4. Column experiment for determining the phosphate removals by the potential filter media selections. ....	17
Figure 5. Results of column tests on the potential media for ditch check filter. Media composition was 92.5% Sand and 7.5% iron (by weight). ....	18
Figure 6. Column experiment results for filter media, S7 sand-iron B, selected for application in the swale ditch checks.....	19
Figure 7. Aerial map showing the locations of the three ditch check sites in the MnDOT swales along TH 5, Stillwater, MN.....	21
Figure 8. Photograph of the iron-enhanced ditch check constructed at site 2 of MnDOT swales, TH5, Stillwater.....	23
Figure 9. Existing ditch check at site 3 of MnDOT swales, TH5, Stillwater. ....	24
Figure 10. Layout of the monitoring system at the iron-enhanced ditch check sites 1 and 2 in MnDOT swales. ....	25
Figure 11. Monitoring system layout (top) and photograph at SAFL of the compound weir setup for measuring outflow (bottom) at the existing ditch check Site 3 in MnDOT swales....	26
Figure 12. Photograph showing the water truck testing conducted at MnDOT iron-enhanced ditch check site 2, TH5 swales, Stillwater. ....	28
Figure 13. Results of synthetic runoff testing at the MnDOT iron-enhanced swale ditch check site 2, on Nov 4, 2014.. ....	30
Figure 14. Sample hydrograph recorded at the MnDOT iron-enhanced ditch check site 2 on June 14, 2015, rainfall event. The composite sampling regime is also shown in the plot.....	32
Figure 15. Exceedance plot for flow volume and corresponding paired phosphate mass loads and mass load reductions at the iron-enhanced ditch check constructed in the MnDOT swales. ....	39
Figure 16. Exceedance plot for flow volume and corresponding paired phosphate mass loads and mass load reductions at the existing ditch check in MnDOT swales.....	41
Figure 17. Comparison of phosphate mass loadings at the enhanced ditch check and existing ditch check in the MnDOT swales for eight storm events monitored in 2015.. ....	43
Figure 18. (a) Map location and (b) Photograph of the Roseville swale basins along Twin Lakes Parkway, Roseville, MN. ....	44
Figure 19. Iron-enhanced ditch check installed at the Roseville swale basin.....	46

Figure 20. Photograph showing the water truck testing conducted at the Roseville iron-enhanced ditch check site on 28 Oct, 2014. ....	47
Figure 21. Field testing conducted at the Roseville ditch check on 30 October, 2014: (a) Measured flow rates and input volume (inflow at 13:20 is out of the scale range); and (b) Measured sample phosphate concentrations (C <sub>in</sub> and C <sub>out</sub> denote concentration in the inflow and filter outflow). ....	49
Figure 22. Results of field testing conducted at the re-installed Roseville ditch check in summer 2015: (a) Test 1 on July 24; (b) Test 2 on August 7; and (c) Test 3 on August 14, 2015. ....	51
Figure A- 1. Engineering drawings of the iron-enhanced ditch check design for the swales at TH5, Stillwater (Courtesy: MnDOT). ....	64
Figure A- 2. (a). Construction stage showing the filter cage enclosure. (b) Completed filter cage enclosure at ditch check site 1. ....	66
Figure A- 3. (a) Construction stage showing the placement of filter bags and filling media within the filter cage enclosure. (b) Completed filter installation at ditch check site 1. ....	68
Figure A- 4. (a). Construction stage showing placement of filter media into a single wrap-bag; (b). Completed filter at ditch check site 2, MnDOT swales. ....	70
Figure A- 5. Construction stage showing the rip rap and river rock layers placed around the filter cage, and drain tile on the downstream side at ditch check site 1, MnDOT swales. ....	71
Figure A- 6. Construction stage showing placement of top soil mix at ditch check site 1, MnDOT swales. ....	72
Figure A- 7. Construction stage showing placement of sod at ditch check site 1, MnDOT swales. ....	72
Figure A- 8. Iron-enhanced ditch check constructed at site 2, MnDOT swales. ....	73
Figure A- 9. Drawings of the aluminum filter enclosure designed at SAFL for the Roseville ditch check. ....	75
Figure A- 10. Mixing of sand and iron shavings in a mortar mix. ....	76
Figure A- 11. Filling filter media mix into the filter socks using the funnel setup at SAFL. ....	77
Figure A- 12. Aluminum frame enclosure affixed in the concrete wall at the Roseville swale site. ....	78
Figure A- 13. Installation of filter socks within the frame enclosure at Roseville swales (first iron-enhanced ditch check installed in October 2014). ....	79
Figure A- 14. Photograph of the completed Roseville iron-enhanced ditch check filter assembly taken in October 2014. ....	79
Figure A- 15. Photograph of the re-installed iron-enhanced ditch check filter at Roseville swales site in July 2015. ....	80
Figure B- 1. Schematic of recommended design for a typical iron-enhanced swale ditch check. (a) Profile view and (b) Cross-sectional view (Section A-A). ....	81

## List of Tables

Table 1. Saturated hydraulic conductivities ( $K_{sat}$ ) of the six sand and sand-iron media samples determined by the constant-head permeability method. ....	12
Table 2. Simulated drain time and pollutant retention at the hypothetical iron-enhanced ditch check. ....	16
Table 3. Characteristics of the TH 5 MnDOT swale sites. Data are derived from the site plans and survey plans provided by MnDOT. ....	22
Table 4. Water quality monitoring data for the Iron-Enhanced Ditch Check (Site 2) in MnDOT swales: <i>EMCs</i> of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd). ....	34
Table 5. Water quality monitoring data for the Iron-Enhanced Ditch Check (Site 2) in MnDOT swales: Total mass in ( $M_{IN}$ ), mass out ( $M_{OUT}$ ) and mass removal ( $M_R$ ) of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd). ....	35
Table 6. Water quality monitoring data for the Existing Ditch Check (Site 3) in MnDOT swales: <i>EMCs</i> of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd). ....	36
Table 7. Water quality monitoring data for the Existing Ditch Check (Site 3) in MnDOT swales: Total mass in ( $M_{IN}$ ), mass out ( $M_{OUT}$ ) and mass removal ( $M_R$ ) of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd). ....	37
Table 8. Summary of dissolved metal <i>EMCs</i> and mass loads at the iron-enhanced ditch check (site 2) in the MnDOT swales monitored for 15 storm events. ....	40
Table 9. Summary of dissolved metal <i>EMCs</i> and mass loads at the existing ditch check (site 3) in the MnDOT swales monitored for 11 storm events. ....	42
Table A- 1. Material specifications for the MnDOT iron-enhanced ditch checks (derived from MnDOT ditch check design plans). ....	60
Table A- 2. Specifications of iron and sand used in the MnDOT ditch check filter (data provided by the manufacturer/distributor). ....	61
Table A- 3. Specifications of geotextile fabric WINFAB 2300 (Data source: <www.winfabusa.com>). ....	61
Table A- 4. Specifications of sand and iron used in the ditch check filter media at Roseville (data were provided by the manufacturer/distributor). ....	74



Table D- 1. Summary of field testing data collected at the iron-enhanced ditch check installed in the City of Roseville swale basin.....	87
Table D- 2. Monitoring data for iron-enhanced ditch check in MnDOT swales in TH5, Stillwater: Part 1 .....	88
Table D- 3. Monitoring data for iron-enhanced ditch check in MnDOT swales in TH5, Stillwater: Part 2 .....	89
Table D- 4. Monitoring data for existing un-modified ditch check in MnDOT swales in TH5, Stillwater: Part 1 .....	90
Table D- 5. Monitoring data for existing un-modified ditch check in MnDOT swales in TH5, Stillwater: Part 2 .....	91

## **Project Summary**

### **Problem**

Roadside swales and ditches are stormwater control measures for conveyance and infiltration of roadway runoff. Runoff contains phosphorus and metals, and the phosphate and dissolved metal forms of these pollutants cause water quality concern due to their increased bioavailability, eutrophication risks, and aquatic toxicity. Removal of phosphate requires advanced treatment using specialized media, which is not part of typical swale-check dam designs. As such, swales retain little, if any, dissolved pollutants. In this project, the iron-enhanced sand filter technology (Erickson et al. 2007; 2012) was applied to design and develop “iron-enhanced ditch checks” for roadside swales, to specifically increase the phosphate and metal retention capabilities of the swales. The iron-enhanced ditch checks fill a vital need for stormwater treatment along roadways, and have the ability to transform existing swales and ditches to high-performance treatment systems which can possibly help gain credits for both infiltration and pollution control through these systems.

### **Waterbody Improved**

Iron-enhanced swale ditch checks were designed and installed as part of roadway projects of the Minnesota Department of Transportation (MnDOT) and the City of Roseville. The study sites are located in Stillwater and Roseville in MN, which are in the Valley Branch Watershed District (VBWD) and Rice Creek Watershed District (RCWD), respectively. Field testing and monitoring showed that the iron-enhanced swale ditch check has a higher potential to remove phosphate in runoff when compared to an existing ditch check that contains no specialized media. The dissolved metal reductions were better at the existing ditch check.

Outflows from the iron-enhanced ditch check in the MnDOT swales drain into Cloverdale Lake, which is classified as a ‘medium priority’ water body as it meets the excellent water quality ranking guidelines for phosphorus (VBWD water management plan, 2005). However, the project sites are in the Valley Branch Watershed District which lies within the St. Croix River watershed that is impaired for nutrients. Runoff from the Roseville swales are finally routed to Long Lake in New Brighton and then to Rice Creek. Long Lake has been listed on Minnesota’s Section 303(d) List of Impaired Waters for nutrients. The Rice Creek Watershed District (RCWD) is currently planning a project aimed at improving the water quality in Long Lake. The RCWD is currently working with the cities of New Brighton and St. Anthony on two stormwater retrofit projects, due 2018, that includes installation of an iron-enhanced sand filter for phosphorus removal (RCWD, <<http://www.ricecreek.org>>).

While overall reduction of dissolved phosphorus loads was achieved through the iron-enhanced swale ditch checks installed in Stillwater and Roseville, effects of the reduction on the water quality of the receiving water bodies was not evaluated.

## Project Highlights

This research project is an US EPA 319 project funded through the Minnesota Pollution Control Agency (MPCA), and involved partnerships between the Minnesota Department of Transportation (MnDOT), the City of Roseville, and the St. Anthony Falls Laboratory (SAFL), University of Minnesota. In this project, a new application of the iron-enhanced sand filter was tested and applied in roadside swales/ditches for advanced treatment of dissolved phosphorus and metals in runoff. After a series of laboratory-scale tests, the iron-enhanced swale ditch check designs were developed, and installed in swales located in the right-of-way of MnDOT and City of Roseville in Fall 2014. The effectiveness of the iron-enhanced swales was investigated by field testing and monitoring during rainfall events in Fall 2014, and Spring and through Summer 2015. Performances of an existing un-modified ditch check located near the MnDOT swale was also tested and monitored for comparison.

## Results

The iron-enhanced swale ditch check in the MnDOT swale was monitored during 17 rainfall events in 2015. Sampling was performed upstream and downstream of the iron-enhanced section (the filter) in order to isolate its performance. Between 15 and 54% of the phosphate mass load received (mean = 33%, median = 37%) was removed by the iron-enhanced ditch check. The lowest reduction (-11%) was observed during an extreme storm event. The cumulative phosphate mass removal was 35% for the monitoring duration. However, reductions of metal mass loads were low (mostly export) for a majority of the events. Field testing using synthetic runoff showed reductions of 78% for phosphate and 11% for zinc at this ditch check. In comparison, the existing ditch check (that contained no iron-enhanced filter media and was monitored upstream and downstream of the ditch check) showed little or no reduction of the phosphate mass loads during the 13 events monitored. Most events were characterized by increased effluent *EMC* and thus negative mass reductions of phosphate mass. Metal mass loads were mixed, but zinc removals were generally positive (mean = 36%). Field testing at the existing ditch check showed reductions of 11% for phosphate and 78% for zinc.

It is believed that the organic compounds in the soil covering the ditch check were responsible for the removal of zinc. The iron-enhanced ditch check monitoring excluded the effect of this soil. It can therefore be presumed that an iron-enhanced ditch check will retain metals in the soil covering the ditch check and retain phosphate in the filter.

The Roseville iron-enhanced ditch check was evaluated by field testing using synthetic runoff. The first two tests in Fall 2014 exhibited average phosphate removals of 19% and 31%; however, water was observed to by-pass treatment due to a leakage in the filter installation.

Therefore the filter was re-installed in July 2015 and re-tested. Under conditions of low flow rates, the average phosphate retentions were 47% at low influent concentrations (100 µg/L), and 43% at higher influent concentrations (300 µg/L). The average phosphate removals were 26% when high phosphate load was input to the ditch check at higher flow rates, which can be attributed to the shorter contact time available for phosphate adsorption by iron under high flow conditions. The Roseville ditch check provided 14% reduction of the zinc mass load input.

Overall, the iron-enhanced swale ditch checks were found to consistently reduce the phosphate mass loads in runoff. The soil of the ditch checks will also retain dissolved metal. Iron-enhanced ditch checks could be installed in series to increase phosphate removal from the runoff. The lessons learnt from the design, construction and performance assessments of the MnDOT and Roseville iron-enhanced swales were utilized towards developing design recommendations for iron-enhanced swale ditch checks for future application.

## **I. Work Plan Review**

Approved changes: Two change orders were approved for this project. In change order #1 of October 2013, the budget for professional services (contract for Prof. Pete Weiss) and travel was adjusted to provide for housing costs for Prof. Weiss. In change order #2 of February 2014, budgetary adjustments were done within the lab services, professional services, capital equipment, and postdoc salary and fringe categories. There were no changes to the original work plan, staff, or participating organizations.

### **Objective 1: Construction**

*Task 1a: Install Iron-Enhanced swales (MnDOT)*

*Task 1b: Install Iron-Enhanced swales (City of Roseville).*

The design of iron-enhanced swale ditch checks was developed by conducting multiple laboratory tests, modeling exercise, and concurrent site selection. Two iron-enhanced ditch checks were constructed at the MnDOT swales in September 2014. An existing ditch check located in the swale was included in the study to compare the pollutant-removal performances of the iron-enhanced ditch checks with the existing ditch checks that contain no specialized media for runoff treatment. The Roseville iron-enhanced ditch check was installed in September 2014. This ditch check was re-installed in July 2015 to fix a leakage issue in the previous installation.

Construction/installation of the iron-enhanced ditch checks was delayed due to numerous iterative design changes. The re-designs were done to address the site conditions, feasibility of constructing the proposed design, and ability to monitor the flow and water quality at the ditch checks. Each re-design exercise involved planning, preparation, laboratory testing, and coordination with the project partners to develop the new design, followed by new pilot-scale testing if needed before application in the field. Wet conditions due to excessive rainfall during spring/summer 2014 and unavailability of construction crew caused further construction delays. A supplementary document detailing the challenges faced was submitted to the project manager, Greg Johnson, in August 2014, along with the semi-annual report for the January 1 to June 30, 2014 reporting period.

The project tasks were completed in spite of the delay in the construction schedule.

### **Objective 2: Conduct Field Monitoring**

*Task 2a: Install monitoring equipment*

*Task 2b: Field monitoring*

*Task 2c: Chemical analysis*

### *Task 2d: Data analysis*

Monitoring equipment was installed at three sites in the MnDOT swales (two iron-enhanced ditch checks and the existing ditch check) in October 2014 after construction was completed in September 2014. Since rainfall did not occur in September and October after the sites were instrumented, field testing using synthetic runoff was conducted at all three sites in November 2014. Field monitoring during storm events was conducted at one iron-enhanced ditch check site and the existing ditch check site from May through August 2015. 17 events were sampled at the iron-enhanced ditch check site and 13 events were sampled at the existing ditch check site. The 2014 field testing and monitoring in 2015 showed that there were issues with flow routing in the second iron-enhanced ditch check and thus this site could not be monitored for water quality performance.

Water samples collected from all sampling events were analyzed for soluble reactive phosphorus (phosphate) at the St. Anthony Falls Laboratory, and for dissolved metals at the Analytical Geochemistry Laboratory at University of Minnesota. The monitoring data collected were analyzed to determine the reductions of event mean concentrations and mass loads achieved through the iron-enhanced ditch check on event- and cumulative-basis. Treatment performances of the iron-enhanced ditch check and existing un-modified ditch checks were also compared.

The development of the final ditch check design for the selected swale sites involved extensive effort and time to accommodate the construction and monitoring needs of the project; however the time spent can be considered as preparation for the field testing and performance monitoring of the ditch checks. Because of the delayed construction of the iron-enhanced ditch checks, the total field-monitoring duration was shorter than the initial work plan. In the first season (fall 2014), field testing using synthetic runoff was conducted instead of field monitoring due to lack of rainfall. Field monitoring was conducted for one season, from May through August 2015. However, monitored data collected provided sufficient information for assessing the ditch check performances. Chemical analysis and data analysis have been completed on-time.

## **Objective 3: Conduct Field Testing**

### *Task 3a: Conduct field testing*

### *Task 3b: Chemical analysis*

### *Task 3c: Data analysis*

Field testing at the Roseville iron-enhanced swale ditch check was conducted using a water truck in October 2014 (two tests), and in July and August 2015 (three tests). In each field test, synthetic runoff was generated by chemically dosing the water in the water truck and the dosed

water was introduced into the swales. Water samples collected throughout the test were analyzed, and the phosphate and dissolved metal retention performances of the iron-enhanced swale determined.

The Roseville swale had unique site conditions and the time spent on designing the ditch check for this location was more than anticipated. Although the field testing conducted for two seasons (Fall 2014, Summer 2015) is shorter than the initial work plan, the iron-enhanced ditch check was subjected to different testing conditions to determine performance under the varying pollutant and hydraulic load conditions. Chemical analysis and data analysis have been completed on-time.

#### **Objective 4: Public Outreach and Education**

*Task 4a: Establish partnerships*

*Task 4b: Dissemination*

*Task 4c: Incorporation into education program*

Several meetings were held with the engineering staff at MnDOT and City of Roseville to ensure the design and construction of the ditch checks met the project objectives. Periodic updates on the project progress and results were shared with the project staff at MnDOT and City of Roseville. The preliminary findings and results of this project have been shared with the public parties via an article in the July 2015 issue of UPDATES, our monthly stormwater newsletter with over 2400 subscribers, and at our project website <http://stormwater.safl.umn.edu/>. Knowledge gained from this project continues to be shared through presentations, workshops, and meetings. A peer-reviewed journal article will be published from the results of this project. In addition, the project results will be incorporated into undergraduate and graduate-level coursework at the University of Minnesota.

#### **Objective 5: Publish Final Design Standards and Final Report**

*Task 5a: Progress reports*

*Task 5b: Prepare and submit design standards for publication*

*Task 5c: Prepare and submit draft final report*

*Task 5d: Prepare and submit final report*

Semi-annual progress reports were submitted twice per year during the project duration, as scheduled. Typical design recommendations for iron-enhanced swale ditch checks were developed based on the project results and are included in this final report. A draft version of the final report was submitted for MPCA's review and the review comments were incorporated into the final report.

## II. Grant Results

### 1. Introduction

Stormwater runoff from paved areas contributes a myriad of pollutants, including heavy metals and phosphorus, to downstream receiving waters. Heavy metals such as cadmium, copper, zinc, are of concern due to their potential toxicity to aquatic species (Jang et al. 2005, Rangsvik and Jekel 2005), and can exist up to 50% in dissolved form (Morrison et al. 1983). On average, 44% of the total phosphorus (TP) load is dissolved (primarily ortho-phosphate, herein labeled phosphate) (Maestre and Pitt 2005; Kayhanian, et al. 2012). In the Twin Cities Metro region, although variable with an average of 40% phosphate to TP ratio, sometimes >90% of the total phosphorus load in the runoff can be phosphates (Erickson et al. 2007). Phosphates are more bio-available (Sharpley et al. 1992) and their increased loads present higher risk of eutrophication of the receiving surface water body. Removal of both particulate and dissolved loads is thus necessary to minimize pollutant bioavailability and control stormwater quality. As an example, reduction of total phosphorus concentration from typical median values of 270 µg/L (Maestre and Pitt 2005; Kayhanian, et al. 2007) to eco-region standards of 20 – 40 µg/L (Northern Lakes and Forests) or less than 100 µg/L (North Central Hardwood Forest) requires advanced treatment for dissolved phosphorus. Therefore, new technologies focusing on dissolved pollutant treatment must be developed to achieve significant improvement in the runoff water quality.

Swales are vegetated channels designed to convey and infiltrate stormwater runoff, and remove the stormwater pollutants primarily by sedimentation, filtration by vegetation, and infiltration of dissolved fractions. A ditch check or check dam is a berm constructed across a swale or ditch to promote additional infiltration, increase storage, and reduce the velocity of water flowing through the grass channel that in turn allows sediments to settle and reduce erosion (U.S. EPA 1999). Ditch checks are typically constructed of rock aggregate or soil (although earthen dams are not recommended due to their potential to erode), and can sometimes be temporary installations made out of straw bales or wood excelsior (bioroll or bioroll blanket), silt fence, geotextile triangular dike, or erosion control engineered products (U.S. EPA 1999; MN LRRB 2003).

Swales have been found to be generally effective in reducing large particles (60-90% for total suspended solids) and metals (18-87% for total zinc and total copper) in stormwater runoff, but show variable treatment of nutrients (export to 60% for total phosphorus and total nitrogen) (Barrett 2008; Yonge 2000; CALTRANS 2004; Ahearn and Tveten 2008). Dissolved pollutants are also generally treated with low to moderate efficiency since their removal is largely dependent on volume reduction by infiltration in the swales (CALTRANS 2004; Barrett 2008). Studies have shown that inclusion of check dams (vegetative or rock or weir dams) appear to have additional, if not substantial, effect on the pollutant treatment



performance of swales due to increased hydraulic retention time of water that promotes sedimentation and infiltration (Kaighn and Yu 1996; Yu et al. 2001; Stagge et al. 2012).

“Iron-enhanced ditch checks” are novel stormwater treatment systems that incorporate filtration media specifically chosen to capture dissolved metals and phosphate. The concept of the iron-enhanced ditch check system is to intercept stormwater runoff as it flows through roadside ditches, allowing particles to settle out of the water column, and capture dissolved pollutants as runoff filters through the filtration media composed of gravel, sand, and adsorption material. A preliminary design of an iron-enhanced ditch check, that employs the iron-enhanced sand filter technology developed by Erickson et al. (2007), was developed and tested in the laboratory through a project funded by the Local Road Research Board (LRRB) (Ahmed et al. 2014). In an iron-enhanced sand filter, as iron oxidizes to form iron oxide (rust), phosphates strongly bind to iron oxides by surface adsorption and this iron-bound phosphate is not bioavailable (Erickson et al. 2007; Erickson et al. 2012). Batch studies have shown potential removal of dissolved metals using iron-based compounds (Ahmed et al. 2014).

The goals of this research project were to design and construct iron-enhanced ditch checks in roadside swales, and evaluate their field performances in treating the dissolved pollutants in roadway runoff. The iron-enhanced ditch checks were designed and constructed in existing ditches/swales as part of MnDOT and City of Roseville roadway projects, and their effectiveness determined by field testing and monitoring during rainfall events. Results obtained were used towards the development of design recommendations for iron-enhanced swale ditch checks for future applications.

The five major objectives and tasks of this project were to:

1. Design and install iron-enhanced swale ditch checks in MnDOT swales and in City of Roseville swales;
2. Conduct field monitoring and assess performances of the MnDOT iron-enhanced swale ditch checks;
3. Conduct field testing and assess performance of the City of Roseville iron-enhanced swale ditch checks;
4. Disseminate project results through public outreach and education initiatives; and
5. Develop recommended typical design standards for iron-enhanced swale ditch checks.

Performances of the iron-enhanced swales were evaluated by a mass-balance monitoring approach, involving flow measurements and water sampling at the inlet and outlet of the ditch check. Field monitoring during natural rainfall-runoff events was performed to determine the effectiveness of the ditch checks in treating the variable pollutant loadings in runoff. Field-testing using synthetic runoff was conducted to assess the pollutant retention performances under controlled conditions.

If found to be effective in capturing dissolved phosphorus and metals, the iron-enhanced ditch check installations will help achieve multiple goals including advanced runoff treatment, erosion control and pollution prevention, and ultimately transform conventional roadside ditches into high-performance swales. These ditch check systems can be applied for stormwater treatment in locations where volume control and infiltration are not feasible due to existing soil conditions or subsurface water quality, as well as in locations where limited right-of-way, cost, or land-development feasibility pose constraints. The design, construction, and performance data obtained from this project will provide information towards developing design standards, and implementing this innovative stormwater treatment system in new or existing roadside ditches.

## **2. Design and Development of Iron-Enhanced Ditch Checks for Roadside Swales/Ditches**

### **2a. Background: Iron-Enhanced Ditch Check Prototype**

Prior to the commencement of this project, laboratory tests were conducted to develop and test an iron-enhanced ditch check prototype through a project funded by the Local Road Research Board (LRRB) (Ahmed et al. 2014). The tests involved (i) batch experiments for selection of filter media enhancement material, and (ii) design and pilot-testing of a ditch check prototype. Several potential sorbing materials including alumina, silica, ferrous oxides, and iron-based materials (iron shavings and steel wool) were tested in a batch study. Iron shavings emerged as one of the final choices due to the high pollutant removal observed, and final solution pH below 10 (which is the MPCA maximum pH for aquatic life and recreation waters). A ditch check prototype consisting of sand-iron filter media was designed and tested in a 20-inch flume at the St. Anthony Falls Laboratory (SAFL). The hydraulic conductivity of the media, composed of 95% C-33 sand and 5% iron shavings (by weight), was 0.019 cm/s (27 in/hr). Rip-rap was placed at a 5:1 slope on either side of the 30.5 cm- (12 inch) filter media enclosed in a geotextile bag. Synthetic stormwater runoff containing median pollutant levels expected in roadway runoff (Maestre and Pitt 2005) was passed through the filter and the steady-state pollutant retention measured. The observed average removals were 23% phosphate and 25% dissolved zinc, although the pollutant reduction measurement was affected by leakage of influent water around the filter bag during the tests. The pollutant retention model (Erickson et al. 2012) predicted that the filter can provide about 60% reduction in pollutant concentrations for the test conditions.

### **2b. Full-Scale Design Components**

For a stormwater treatment practice like grass swales/drainage ditches that incorporates plants, the impounded runoff is recommended to drain within 48 hours (Erickson et al. 2013). However, it is important to balance the drain time and the contact time of runoff with iron to achieve both infiltration and pollutant removal objectives at the ditch checks. Therefore,

changes were made to the iron-enhanced ditch check prototype tested by Ahmed et al. (2014). It was proposed to replace the finer C-33 sand used in the lab prototype with a coarser sand gradation, keeping in mind maximum pollutant reduction needed to be achieved. Laboratory tests on new sand and iron samples, and simultaneous modeling exercises were performed to select a new filter media and determine other design parameters for the iron-enhanced ditch checks to be constructed in the study sites.

#### *i. Permeability tests on filter media*

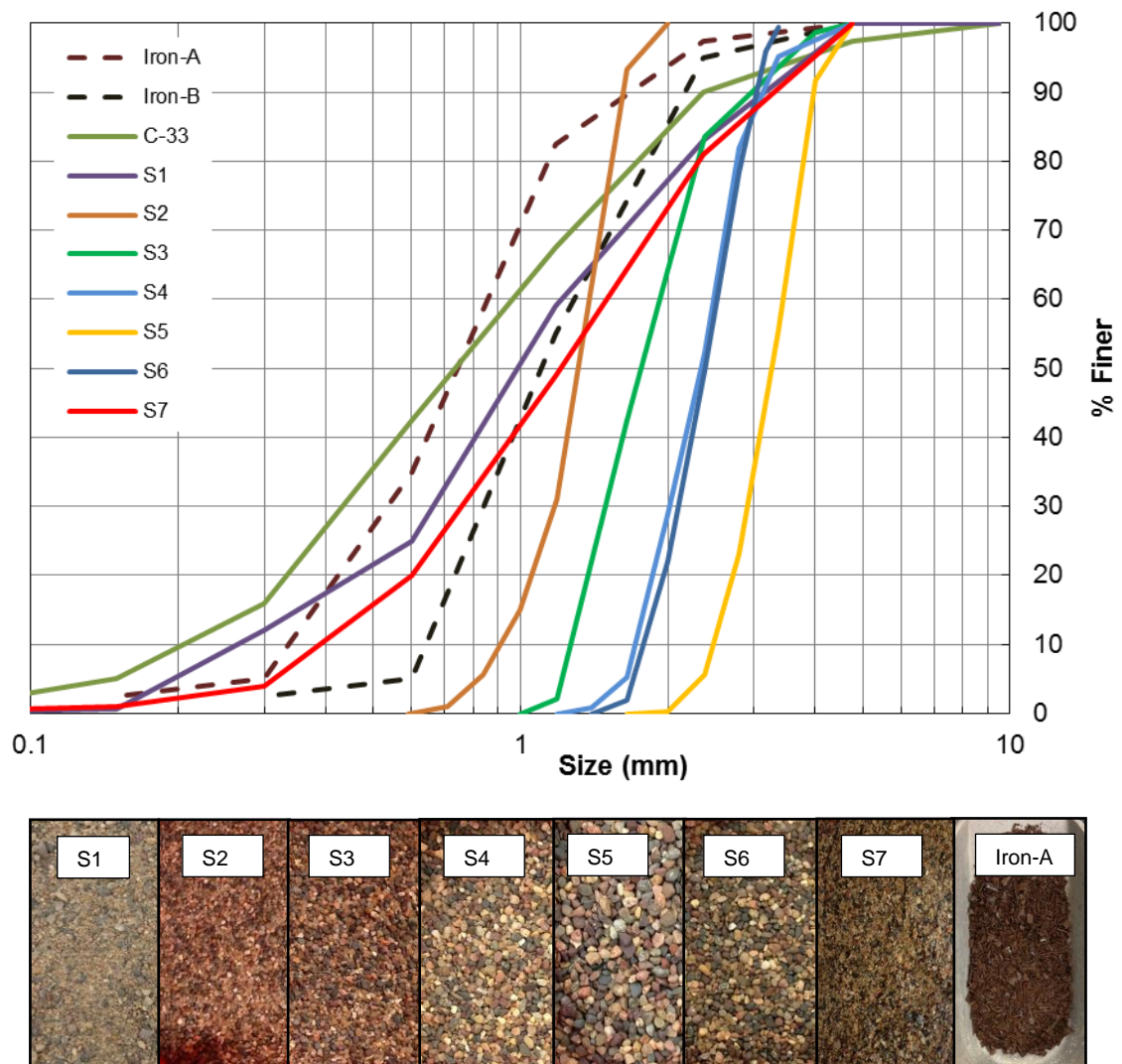
Six sand samples of various particle size gradations (S1 to S6;

Figure 1) were selected as potential filter media. The saturated hydraulic conductivities of 100% sand, and 95% sand-5% iron shavings (type A, Figure 1) media were determined by the constant-head permeability test (ASTM 2006) (Figure 2).

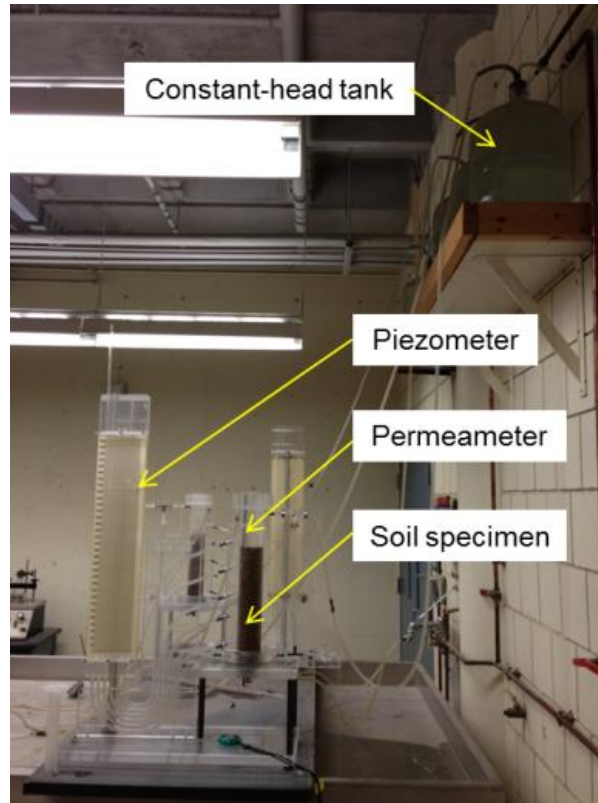
In the constant-head test, a weighed quantity of media was filled into a 6 cm (2.4 inches) diameter permeameter column in incremental quantities, compacted using a hand tamper tool at each increment, and filled to a total height of 30 cm (12 inches) in the column. Tap water was passed from the top of the column and allowed to saturate the media. Periodic measurements of piezometric water level at various sections of the column and discharge rate were taken. The establishment of constant gradient or steady state condition was indicated by constant readings in the piezometer. The steady-state head and discharge measurements were utilized to compute the saturated hydraulic conductivity of the media using Darcy's law:

$$K_{sat} = \frac{Q L}{\Delta h A} \quad (1)$$

where,  $K_{sat}$  is the saturated hydraulic conductivity,  $Q$  is the discharge rate,  $L$  is the distance over which the difference in head,  $\Delta h$ , is measured, and  $A$  is the cross-sectional area of the column.



**Figure 1. Particle size distribution and photographs of the sand and iron shavings samples tested for application as filter media in the iron-enhanced ditch check. The particle size distribution of C-33 sand is provided for reference.**



**Figure 2. Constant-head permeability test setup used for measuring the saturated hydraulic conductivities of sand samples.**

The measured  $K_{sat}$  of the sand samples tested ranged between 0.022 and 0.484 cm/s (32 and 686 in/hr) (Table 1). The  $K_{sat}$  values of sand-iron media were lower than the sand-only media due to the fact that the finer iron shavings occupied the interstitial space between sand particles, thereby reducing the overall hydraulic conductivity of the sand-iron mix. No wash-out of iron shavings was observed for the sand-iron mix samples tested. The wash out was tested by collecting the discharge from the column into a small bucket throughout the test period, visually inspecting for presence of iron particles, and re-checking while pouring out the water into a wide metal basin by the test apparatus.

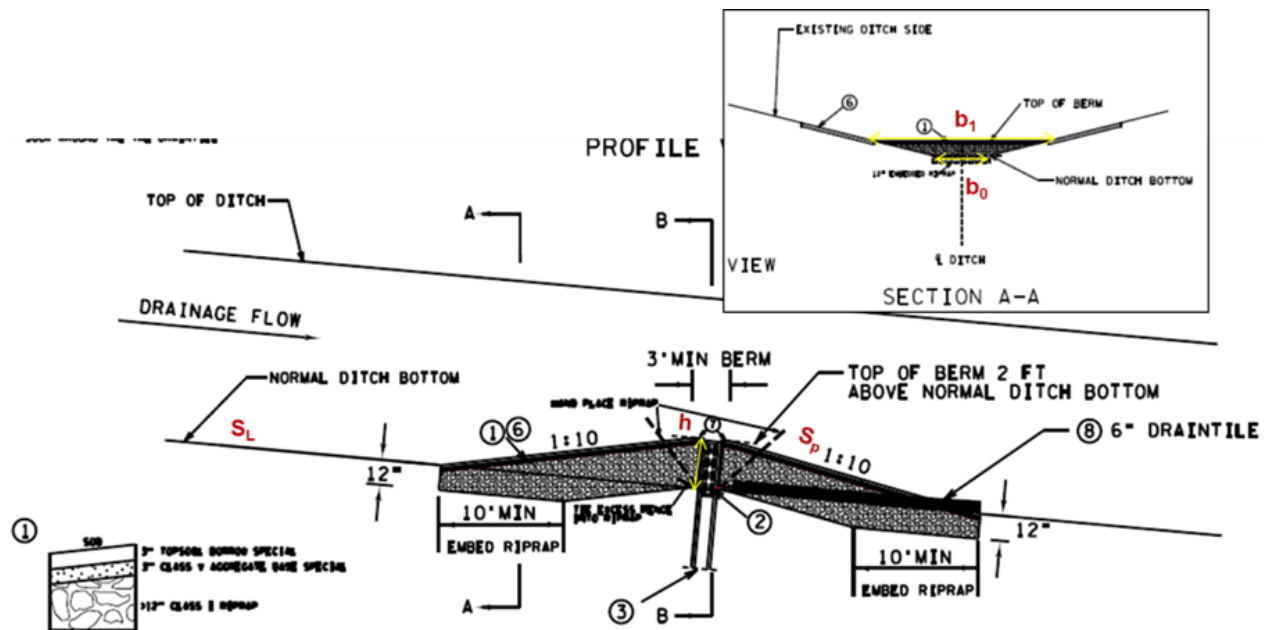
**Table 1. Saturated hydraulic conductivities ( $K_{sat}$ ) of the six sand and sand-iron media samples determined by the constant-head permeability method. (Conversion: 1 cm/s = 1417 in/hr)**

Media	S1	S2	S3	S4	S5	S6
$K_{sat}$ (cm/s) of 100% sand	0.0229	0.0798	0.1280	0.1632	0.3831	0.1644
$K_{sat}$ (cm/s) of 95% Sand - 5% Iron-A	0.0075	0.0528	0.1117	0.1032	0.1074	0.1032

## ii. Drain time modeling

The media hydraulic conductivity results obtained were used in conjunction with a drain time model that simulates the time taken for a given volume of water to drain through the ditch check and the concomitant pollutant removal achieved. The pollutant removal and water drain rate results were used towards selecting the media for the next phase of laboratory tests.

The modeling was done for a hypothetical ditch check, which was based on the preliminary design proposed for the potential study site at the MnDOT swales. The schematic diagram and summary of design parameters of the hypothetical ditch check are provided in Figure 3. The length of filter media in the ditch check is 30.5 cm (12 inches) in the direction of flow.



Parameters	
Normal ditch bottom slope ( $S_b$ )	1%
Face slope of berm ( $S_p$ )	1:10
Height of berm ( $h$ )	0.46 m (1.5 ft)
Bottom width of ditch ( $b_0$ )	3 m (10 ft)
Width at top of berm ( $b_1$ )	7.9 m (26 ft)

**Figure 3. Schematic of the profile and sectional views of the hypothetical iron-enhanced ditch check design used for the drain time modeling exercise. Design parameters of the ditch check are tabulated.**

The drain time for the water detained at the ditch check after runoff to the site has ceased was modeled. As water drains through the ditch check filter, the flow is not under a steady state condition because the upstream head and the flow through the filter are decreasing over time. Assuming quasi steady-state, where the response of the flow in the filter to the head variation is quick, the flow and pollutant model simulations were performed over small time intervals, assuming the flow is steady-state during this time interval. The volume balance for the water stored at the ditch check is:

$$\text{Change in storage} = \text{Inflow rate} - \text{Outflow rate} \quad (2)$$

$$\frac{dV}{dt} = -Q_{out} \quad (3)$$

$$\int_{V_{max}}^{V_{min}} dV = \int_{t=0}^{t=T} -Q_{out} dt \quad (4)$$

$$V_{t+1} = V_t + dV \quad (5)$$

In equations 2 through 5,  $V$  is the volume of water stored, which is a function of upstream height of water ( $h_0$ ). At start time ( $t = 0$ ), the upstream water height is at the top of the ditch check filter and the corresponding volume of stored water is  $V_{max}$ . At the end of drain time ( $t = T$ ), the stored volume is  $V_{min}$ , which is zero or a small-quantified volume.  $Q_{out}$  is the flow through the filter estimated by the Dupuit equation (Freeze and Cherry 1979), which computes the flow through the filter ( $Q$ ) as a function of the saturated hydraulic conductivity of the media ( $K_{sat}$ ), upstream head ( $h_0$ ) and downstream head ( $h_d$ ) of water at the filter, and size of the filter *i.e.* length in the direction of flow ( $L$ ) and width ( $B$ ), given by:

$$Q = \frac{K_{sat}}{2L} (h_0^2 - h_d^2) B \quad (6)$$

As per concurrent design development, the filtration media was proposed to be enclosed within geotextile fabric socks in the ditch check. The equivalent hydraulic conductivity of the filter ( $K_{eq}$ ) (accounting for media and the geotextile layer) was used for  $K_{sat}$  in equation 6.  $K_{eq}$  was computed as (Freeze and Cherry 1979):

$$K_{eq} = \frac{d}{\left[ \sum \frac{d_g}{k_g} + \sum \frac{d_m}{k_m} \right]} \quad (7)$$

where,  $d$  is the total thickness of the filter,  $d_g$  and  $d_m$  are the respective individual thickness of the geotextile fabric and media, and  $k_g$  and  $k_m$  are the saturated hydraulic conductivity of the geotextile fabric and media, respectively. The summations in equation 7 represent the number of layers of geotextile and media present in the filter. As an example, the  $K_{eq}$  of 30-cm filter media in geotextile socks is 0.103 cm/s (146 in/hr), for  $k_m$  of 0.103 cm/s (146 in/hr) and  $k_g$  of 0.13 cm/s (184 in/hr). As expected, the geotextile layers have negligible impact on the overall hydraulic conductivity of the filter media.

The downstream height of water ( $h_d$ ) was assumed to remain constant throughout the simulation period, and three scenarios were simulated: 2.54 cm (1 inch), 1.27 cm (0.5 inch), and zero assuming the water leaves the site fast enough and does not accumulate to a measurable depth. The drain time was calculated until the upstream volume  $V_{min} = 1\%$  of  $V_{max}$ . The 1% assumption is reasonable considering the fact that as time progresses, the difference between the upstream and downstream heads becomes smaller and thus the final small volume will take much longer to drain. The final small volume may in fact infiltrate into the swales, which was not accounted for in the drain time calculation.

The pollutant retention model developed in the LRRB project (Ahmed, et al. 2014) was utilized to estimate the dissolved pollutant removal from the water impounded at the ditch check. Pollutant removal at the ditch check during the course of rainfall event and due to infiltration of runoff was not considered in the computations. Assuming the pollutant mass accumulated in the media was insignificant for the simulation period, the pollutant fraction retained at the ditch check filter was obtained as (Ahmed et al. 2014; Erickson et al. 2012):

$$FR = \left( \frac{C_{in} - C_{out}}{C_{in}} \right) = (0.984)(1 - e^{-0.919 t_{contact}}) \quad (6)$$

The contact time with iron only ( $t_{contact}$ ) was calculated as (Erickson et al. 2012):

$$t_{contact} = T_{media} \times \text{porosity of media} \times \frac{\text{Surface area}_{iron}}{\text{Surface area}_{total}} \quad (7)$$

Media porosity of 30% and surface area ratio corresponding to 5% iron (by weight) were used in the contact time calculation. The retentions computed at each time interval were flow-weighted over the total drain time to compute the average pollutant fraction retention achieved through the filter. For the ditch check design in Figure 3, the  $V_{max}$  is 27 m<sup>3</sup> (948 ft<sup>3</sup>), which corresponds runoff depth of 0.9 cm (0.35 inch) over an area of 2.9 ha (0.74 ac). Simulation results of the estimated drain time and corresponding pollutant retention (FR, as defined in equation 6) for this volume at the hypothetical ditch check are summarized in Table 2.



**Table 2. Simulated drain time and pollutant retention at the hypothetical iron-enhanced ditch check.**

Media, $K_{eq}$ (cm/s)	Drain Time (hr)	Pollutant Fraction Retention (FR)	Downstream condition $V_{min} = 0.27 \text{ m}^3$
S2-5% iron A, 0.0528 cm/s	74.6	0.6402	$h_d = 0$
	75.6	0.6407	$h_d = 1.27 \text{ cm}$
	78.8	0.6420	$h_d = 2.54 \text{ cm}$
S3-5% iron A, 0.1117 cm/s	9.60	0.2620	$h_d = 0$
	9.62	0.2623	$h_d = 1.27 \text{ cm}$
	9.65	0.2631	$h_d = 2.54 \text{ cm}$
S4-5% iron A, 0.1032 cm/s	10.75	0.2864	$h_d = 0$
	10.76	0.2868	$h_d = 1.27 \text{ cm}$
	10.80	0.2878	$h_d = 2.54 \text{ cm}$

Based on the measured  $K_{sat}$  values and results of the drainage time simulation, media containing S3 and S4 sand were considered as the potential choices for the filter media for the ditch check and were subjected to further testing.

### iii. Column tests

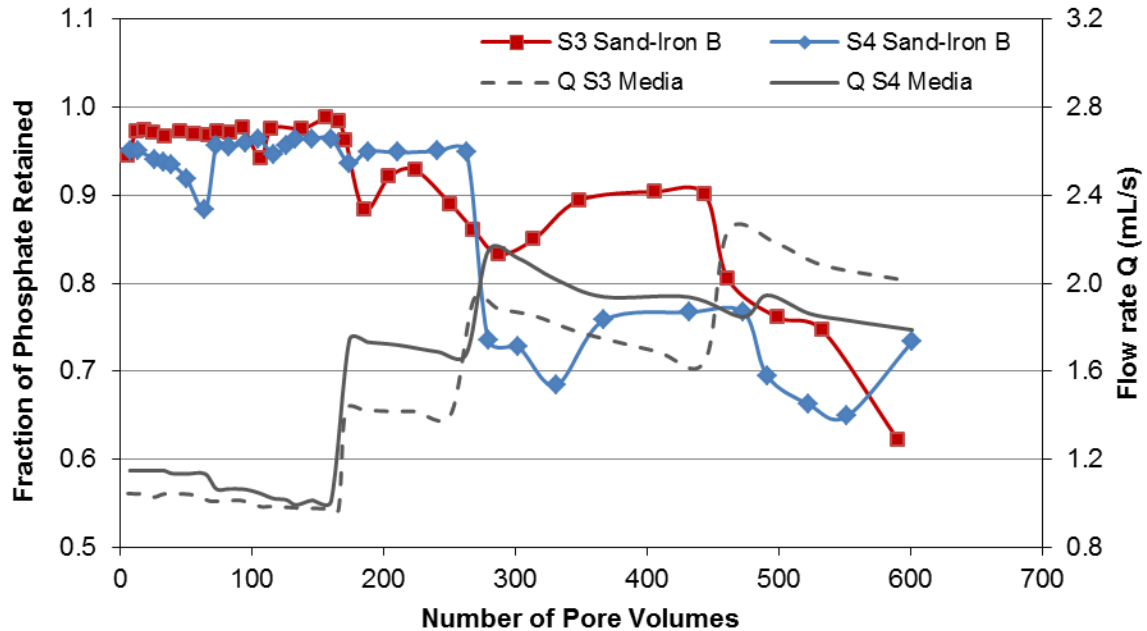
Column tests were conducted to measure the phosphate removal performances of the filter media choices. Two media mixes were tested: S3-Iron B and S4-Iron B, where the iron content was 7.5% by weight (Figure 4). Iron B, which is a coarser gradation of iron shavings compared to Iron A (Figure 1), was used in the column tests. The 7.5% by weight iron proportion was based on the full-scale design being developed concurrently. A control column consisting of 100% S3 sand was also tested. The media was packed in an upward flow column of 5.04 cm (2 inch) diameter and 38 cm (15 inches) length. Layers of washed-pea gravel (approximately 7 cm thick) and woven geotextile fabric were placed on both ends of the media (~24 cm) to prevent resuspension/wash out of media.



**Figure 4. Column experiment for determining the phosphate removals by the potential filter media selections.**

Each media column was subjected to varying flow rates (1.0 to 2.2 mL/s), test durations (1 to 3 hours), and drying times between successive runs (1 to 7 days). Tap water contains an average phosphate concentration of 170  $\mu\text{g/L}$  and was used as the water supply for the column tests. The head loss, outflow rate, water temperature, and water pH measurements were taken during each test. Water samples were collected from the supply tank (inflow) and column discharge (outflow) every 20 or 30 minutes. The water samples were filtered through a 0.45 micron membrane filter and tested for phosphate (soluble reactive phosphorus) concentrations by colorimetric method using ascorbic acid (Standard Methods, APHA 1995) in a Lachat autoanalyzer at SAFL.

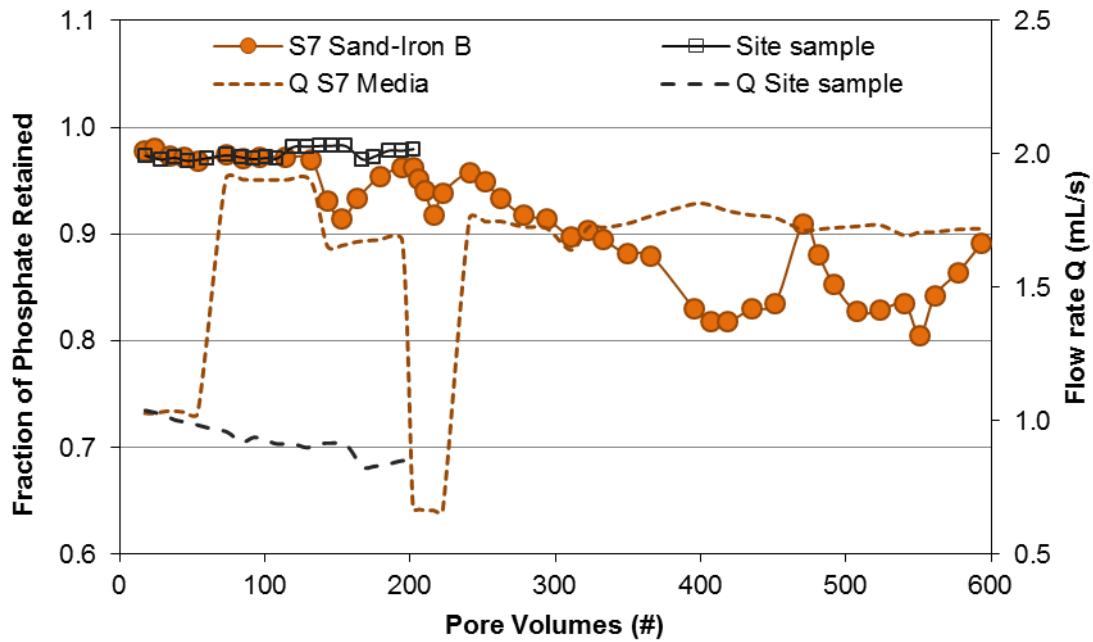
The observed phosphate retentions ranged from 97 to 62% for S3-Iron B media and 95 to 65% for S4-Iron B media during the six tests conducted over two-month period (Figure 5). The control sand-only column showed less than 2% reduction of the input phosphate in the first and second tests, hence further tests on the sand column were not continued.



**Figure 5. Results of column tests on the potential media for ditch check filter. Media composition was 92.5% Sand and 7.5% iron (by weight).**

During the course of the column tests, it was discovered that S3 and S4 sand were not available from a MnDOT-approved vendor in Minnesota. Materials are required to be procured from MnDOT-approved vendors for MnDOT construction projects. Therefore, a new sand sample (S7) was acquired from a MnDOT-approved vendor; the particle size gradation of S7 sand is provided in Figure 1.

Column tests conducted on S7 sand-iron B media (iron content 7.5% by weight) showed good phosphate retentions in the media during the two-month test period. The fraction of phosphate retained for the total pore volumes of water passed through the media is shown in Figure 6. For the input phosphate concentration of 200  $\mu\text{g/L}$  and flow rates ranging between 0.83 and 2.5 mL/s in nine tests (total # pore volumes = 598), the media retained 98 to 84% of input phosphate. The average media hydraulic conductivity was measured to be 0.0586 cm/s (83 in/hr). A small reduction in  $K_{\text{sat}}$  of the media was observed during the test course, likely due to rusting of iron that can enable the occupation of pore spaces. Due to the good phosphate removal capability observed, the S7 sand-iron shavings B media was the final choice for application in the iron-enhanced ditch check to be constructed.



**Figure 6. Column experiment results for filter media, S7 sand-iron B, selected for application in the swale ditch checks. ‘Site sample’ is the media (S7 sand-iron A) actually installed in the MnDOT swale sites. Fraction of phosphate retained =  $\frac{(C_{in}-C_{out})}{C_{in}}$ , where  $C_{in}$  and  $C_{out}$  are the inflow and outflow phosphate concentrations, respectively.**

As will be mentioned later, iron B was not available from the vendor at the time of material order placement. Therefore, iron A was used in place of iron B in the filter media purchased for the MnDOT swales. A sample of this filter media (93% sand, 7% iron A by weight) was collected from the construction site (indicated as ‘site sample’ in Figure 6) and subjected to short-term column tests at SAFL. The saturated hydraulic conductivity of the media was determined to be 0.046 cm/s (79 in/hr), and the average phosphate retention was 97.5% over the one-month test period (Figure 6).

#### *iv. Ditch Check Filter Configuration*

It was proposed to place the filter media as ‘filter socks’ within the ditch checks. A woven geotextile fabric was considered for the filter sock material, and factors such as larger mesh size to prevent clogging by sand, higher permeability to allow free flow of water, and durability against degradation by biological and UV light exposure were among the criteria of selection. A woven geotextile fabric with an apparent opening size (AOS) of U.S. Sieve No. 30 (0.6 mm) and permeability of 0.13 cm/s (184 in/hr) (per manufacturer product data sheet), was chosen as the fabric for the filter socks.

A layout consisting of two rows of 15.2 cm (6 inches) diameter filter socks was proposed, such that the total filter media depth is at least 30.5 cm (12 inches) in the direction of flow. The two-row arrangement was proposed to achieve good overlap of filter material. A frame enclosure around the filter socks was proposed to prevent the socks from dislocating. The filter socks were to be installed within a rip-rap dam, which would then be covered with top soil.

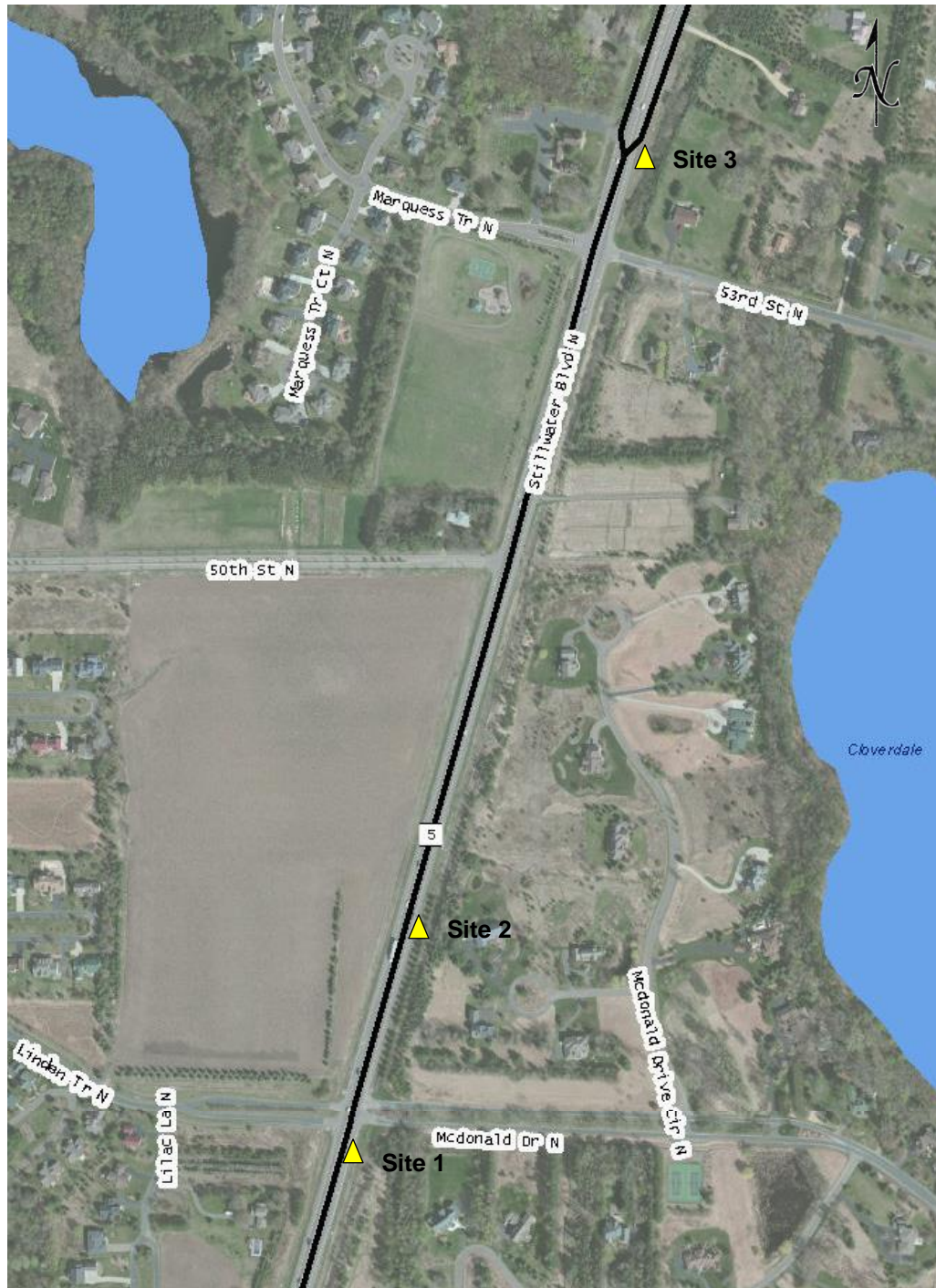
The proposed design recommendations were adjusted to accommodate the site conditions and monitoring/testing objectives at the MnDOT and City of Roseville swales. Appendix A must be referred to for a detailed account on the final design and installation procedure of the iron-enhanced ditch checks at the MnDOT and City of Roseville swales.

### **3. Iron-Enhanced Ditch Checks for MnDOT Swales**

#### **3a. Site Description**

Three swales located along TH 5 in Stillwater, MN, were selected as the study sites (Figure 7). These swales are in the right-of-way of MnDOT. Characteristics of the swale sites are summarized in Table 3. The swales generally have a U-shaped cross-section, and already contain check dams composed of a soil berm underlain by a non-woven geotextile fabric. Two sites in one swale were chosen for the installation of the iron-enhanced ditch check (referred to as iron-enhanced swale Site 1 and Site 2 in this report). The existing soil berms were fully reconstructed to build the iron-enhanced ditch checks at these sites. The third site was chosen to serve as the ‘base-case’ of existing MnDOT ditch checks in the area, which have not been specifically designed for iron-enhanced runoff treatment. No re-construction was performed at this existing ditch check, hereafter referred to as existing swale ditch check Site 3.





**Figure 7. Aerial map showing the locations of the three ditch check sites in the MnDOT swales along TH 5, Stillwater, MN. Site 1 and site 2 are the locations of iron-enhanced ditch checks, and Site 3 is the existing ditch check (soil berm) in the swales.**

**Table 3. Characteristics of the TH 5 MnDOT swale sites. Data are derived from the site plans and survey plans provided by MnDOT. (Conversion: 1 ha = 2.47 acre)**

	Site 1	Site 2	Site 3
Drainage area (ha)	Total = 0.30 Pervious = 0.21 Impervious = 0.09	Total = 0.29 Pervious = 0.21 Impervious = 0.08	Total = 0.22 Pervious = 0.12 Impervious = 0.10
Weighted curve number	79	78	83
Time of concentration	7 min	7 min	7 min
Average ditch width	6.4 m (21 feet)	3.8 m (12.5 feet)	--
Average ditch slope (m/m)	0.008	0.006	0.013

### **3b. Design and Construction of Ditch Checks at MnDOT Swales**

#### *i. Ditch Check Site 1 and Site 2*

The design of the iron-enhanced ditch checks for the MnDOT swales at TH5, Stillwater, underwent several iterations. The re-designs were primarily done to address the site conditions, feasibility of constructing the proposed design, and ability to monitor flow and water quality at the ditch checks. The unusually wet conditions caused by the higher than normal rainfall throughout spring and summer 2014 prevented construction activities to proceed. The iron-enhanced ditch checks were constructed in September 2014 by a MnDOT maintenance crew under the supervision of the MnDOT Water Resources Division. Dr. Natarajan was present representing the University of Minnesota to answer any questions. The construction duration was September 15 to 26, 2014.

Due to last-minute unavailability of iron shavings B at the time the material was ordered, iron shavings A was used in the filter mix for the MnDOT iron-enhanced ditch checks. The filter media mix, consisting of 93% sand and 7% iron shavings (by weight), was directly purchased from a MnDOT-approved vendor. A brief description of the overall design and construction of the ditch checks is provided in this section. Detailed description of the ditch check construction, including design plans, material specifications, and photographs are provided in Appendix A.

The existing ditch checks (soil berms) at sites 1 and 2 were completely dug out and the new iron-enhanced ditch checks were constructed in their place. At site 1, the filter bags were arranged within a metal cage. The void space between and around individual filter bags was filled with loose filter media throughout the installation process. At ditch check site 2, a modified version of the filter was installed. Instead of using several small filter bags, a single geotextile bag was used to contain the filter media. The final filter size in the direction of flow was approximately 0.4 m (17 inches) at both sites. Class I riprap was placed at a 1:10 slope on either side of the filter assembly to build the berm, over which Class V aggregate base was placed to a thickness of 8 cm (3 inches). The gaps between riprap and filter cage fencing were

filled with river rock. The ends of the filter cage were backfilled with bentonite to prevent bypass of water around the filter. The entire berm was covered by 8 cm- (3 inch-) thick layer of special topsoil mix. The top soil mix consisted of 60% C-33 sand, 30% topsoil, 10% peat moss (by volume) at site 1, and 60% C-33 sand, 30% topsoil, 10% compost (by volume) at site 2. Erosion control sod was placed as the uppermost layer and watered periodically after construction for two weeks. A 10 cm (4 inch) diameter drain tile was included on the downstream end of the ditch checks to route water draining through the filter. Monitoring wells (10 cm diameter) were installed on the upstream and downstream sides of the ditch check at the lowest point of the ditch check (along the centerline), as part of the monitoring plans.

The overall construction procedure followed was similar for site 1 and site 2, except for the modification in the filter assembly (i.e. multiple filter bags vis-à-vis single bag). The total length of the iron-enhanced ditch check feature is 13 m (44 ft) in the direction of flow, at both site 1 and site 2. The elevation of the ditch checks is 61 cm (2 ft) above the normal ditch bottom. The width across the ditch (perpendicular to flow) is 6 m (21 ft) at site 1, and 4 m (12.5 ft) at site 2. A photograph of the completed iron-enhanced ditch check at site 2 is shown in Figure 8.



**Figure 8. Photograph of the iron-enhanced ditch check constructed at site 2 of MnDOT swales, TH5, Stillwater.**



## *ii. Ditch Site 3*

The construction at Site 3 was mainly “repair”, which involved correcting the soil berm elevation, re-seeding, placement of a new erosion control blanket and installation of a 10 cm- (4 inch-) diameter PVC drain pipe on the downstream end. Monitoring wells were not installed at this location, as done for sites 1 and 2. The drain pipe was used for flow monitoring purpose at this site. Photograph of the repaired ditch check site 3 is shown in Figure 9.



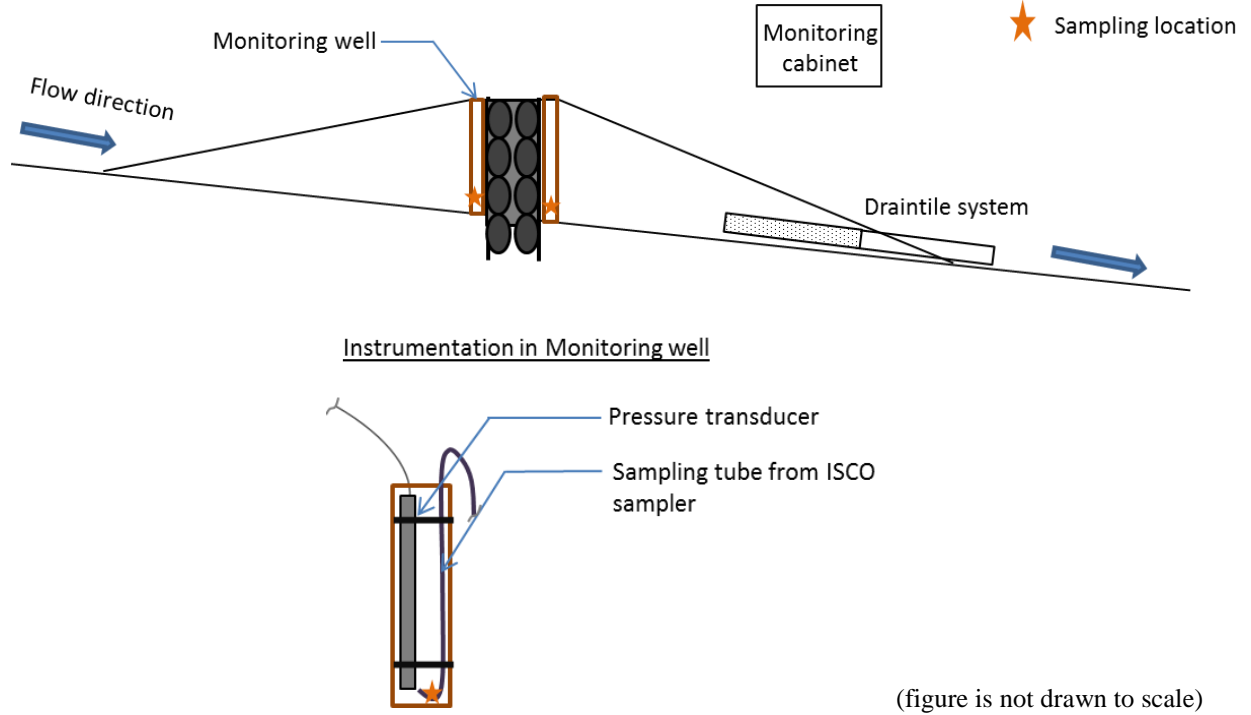
**Figure 9. Existing ditch check at site 3 of MnDOT swales, TH5, Stillwater.**

## **3c. Methods and Measurements**

### *i. Monitoring Method*

Performance monitoring at the MnDOT swale sites was planned for natural rainfall events. At the iron-enhanced ditch check sites 1 and 2, pressure transducers were installed in the monitoring wells to measure the upstream and downstream water levels. The pressure transducer models used were INW PS9105 (Kirkland, WA), and Druck 1830 (GE Measurement and Control). Water sample collection was done at the monitoring wells using

the automated 6700 ISCO samplers (Teledyne ISCO, Lincoln, NE). The overall layout of the monitoring system employed at ditch check sites 1 and 2 is shown in Figure 10.



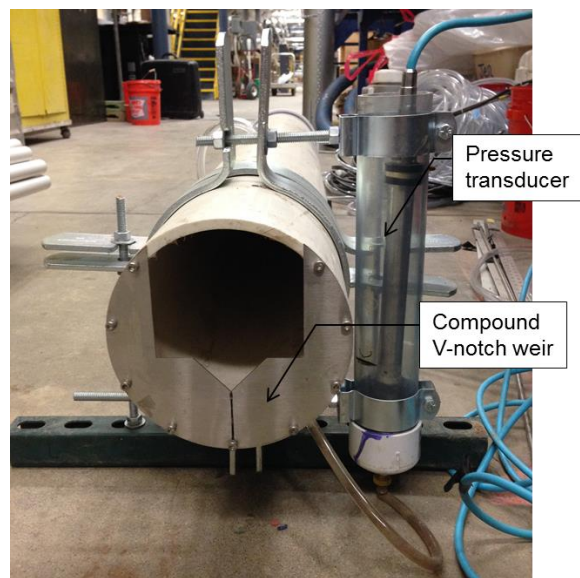
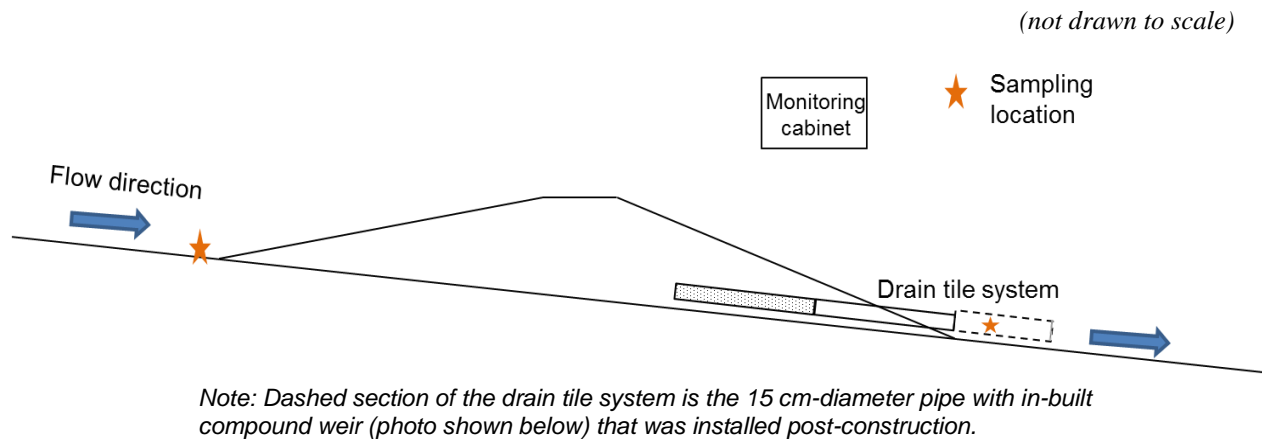
**Figure 10. Layout of the monitoring system at the iron-enhanced ditch check sites 1 and 2 in MnDOT swales.**

The pressure transducers and control cables from the ISCO samplers were connected to a CR1000 data logger (Campbell Scientific, Logan, UT). The measured water levels were used to calculate the flow through the ditch check using Dupuit's equation within the data logger program as:

$$Q = \frac{K_{sat}}{2L} (h_0^2 - h_d^2) \times B \quad (8)$$

where,  $Q$  is flow through the filter,  $K_{sat}$  is the saturated hydraulic conductivity of the media (determined under laboratory conditions),  $L$  is length and  $B$  is the width of the filter in the direction of flow,  $h_0$  is the upstream head, and  $h_d$  is the downstream head of water. The data logger was programmed to trigger the sampling program when flow rate through the filter reached 0.015 L/s (0.24 gal/min) corresponding to a given head of water upstream. Since an impermeable sheet was laid under the filter media during construction, it is assumed that no infiltration occurs at the filter location. This means that the inflow and outflow volumes, computed from the flow rate through the filter over the storm duration, are equal.

At site 3, measurements of flow through the existing ditch check were made in the drain tile on the downstream end. It was assumed that water does not infiltrate underneath the ditch check, and the volumes of runoff entering and leaving the ditch check are the same. Therefore, only the outflow from the ditch check was monitored. A 15 cm (6 inch) pipe section with a compound V-notch weir was constructed and calibrated at SAFL (Figure 11). This pipe section was attached to the existing 10 cm (4 inch) drain tile on site using an eccentric pipe expander. Water level behind the compound weir was measured using INW 9805 pressure transducer installed within the stilling well, and the flow rate computed using the weir calibration equation programmed in the CR1000 data logger. Water quality sampling was performed at the upstream grass channel just before the ditch check (for inflow sample) and at the downstream drain tile (for outflow sample) using ISCO water samplers, as shown in the layout in Figure 11.



**Figure 11. Monitoring system layout (top) and photograph at SAFL of the compound weir setup for measuring outflow (bottom) at the existing ditch check Site 3 in MnDOT swales.**

Volume-based sampling was adopted for water quality monitoring at all three site locations. The data logger was programmed to pass a pulse to the ISCO samplers every time the preset volume of runoff passed through the ditch check filter. The value of this preset volume spacing was determined based on the predicted depth of the rainfall-runoff event (usually obtained at <[www.wunderground.com](http://www.wunderground.com)>), so that the samples collected were representative of the entire rainfall event. The volume-weighted composite samples were collected into a single 9 L (2.5 gallon) glass container.

The monitoring equipment was housed in weather-proof cabinets at the sites. A tipping bucket rain gauge (0.025 cm or 0.01 inch sensitivity) was installed on top of the monitoring cabinet at Site 3. The water levels, flow rate, flow volumes, and rainfall depths at the swales sites were recorded at 5-minute intervals by the data logger during each rainfall event. All instruments were calibrated prior to field installation. The containers used for water sampling were cleaned by acid-washing and dried before each use. Nitrile gloves were worn at the time of handling the sample containers.

## *ii. Field Testing*

Rainfall did not occur during the 2014 season after construction was completed at the MnDOT swales. Therefore, field testing using synthetic runoff (Erickson, et al. 2013) was conducted at each site in November 2014 (Figure 12). A water truck of capacity 23 m<sup>3</sup> (6000 gal) was used. Synthetic runoff was generated by dosing the truck water with a chemical solution containing measured amounts of phosphorus and zinc to attain a target concentration of 220 µg/L phosphate and 150 µg/L zinc in the water. A hose was attached to the spout on the back of the water truck to deliver the synthetic runoff into the swales, approximately 3 m (10 feet) upstream of the ditch checks. The water input rate was controlled by the valve on the spout, and a water meter was connected to the hose to quantify the volume of water being input over time. The equipment and sampling program designed for storm monitoring (described in ‘monitoring method’ section) were utilized to record flows and collect inflow and outflow water samples during the water truck testing.





**Figure 12. Photograph showing the water truck testing conducted at MnDOT iron-enhanced ditch check site 2, TH5 swales, Stillwater.**

### *iii. Analytical method*

Water samples collected at the monitoring sites were transported to the Wet Chemistry Laboratory at SAFL within 24 hours after the runoff flows had ceased at the ditch checks. Duplicate samples of the inflow and outflow were filtered through a 0.45 micron membrane filter to remove the particulates, and the filtrate was frozen until analysis. Phosphate (soluble reactive phosphorus) analysis was performed by direct colorimetry using the ascorbic acid method (Standard Methods, APHA 1995) in a Lachat Quickchem FIA autoanalyzer at SAFL. Dissolved metal concentrations were determined by the ICP-MS method at the Analytical Geochemistry Laboratory at University of Minnesota. The analytical limits of detection are 1  $\mu\text{g/L}$  for phosphate, 0.10  $\mu\text{g/L}$  for copper (Cu), 0.010  $\mu\text{g/L}$  for lead (Pb), 0.10  $\mu\text{g/L}$  for zinc (Zn), and 0.011  $\mu\text{g/L}$  for cadmium (Cd).

### *iv. Data analysis*

A new rainfall event was defined as an event occurring six hours after end of the previous event (i.e. last rain gauge record of first event). On some occasions, a new rainfall event occurred while runoff flows from the previous event were still continuing at the ditch check, and the water quality samples collected were composite samples from both events. Rainfall

depths and flow volumes of the two events were combined, and the data point was analyzed as one water quality event. For certain large rainfall events, sample collection was performed in two parts to cover the entire runoff flow from the event (i.e. composite water samples were collected into two separate 9 L containers). The water quality data of the two samples were utilized to compute the net performance of the ditch check for the entire event. Only one such instance occurred at the MnDOT swale sites during the July 6, 2015, rainfall event (rainfall depth = 10.4 cm or 4.1 in) when a single *EMC* was computed from two measured *EMCs*.

The performance of the ditch check was evaluated by comparing the influent and effluent event mean concentrations (*EMCs*), mass reduction efficiency, and comparison of discharge *EMCs* to water quality criteria. The 100 µg/L criterion for North Central Hardwood Forest was considered as the threshold phosphate concentration in this project. The criteria chosen for metals based on MPCA's water quality standard (chronic standard) for Class 2 waters of the state for aquatic life and recreation are: 106 µg/L Zn, 9.8 µg/L Cu, 3.2 µg/L Pb, 1.1 µg/L Cd (MPCA 2008).

Event mean concentration (*EMC*) represents the average concentration that would result if all the flow were collected into a single container (Davis 2007, Erickson et al. 2013). *EMC* (µg/L) was defined as:

$$EMC = \frac{\text{Total Pollutant Mass}}{\text{Total Volume}} = \frac{M}{V} = \frac{\int_0^T Q C dt}{\int_0^T Q dt} \quad (9)$$

where,  $Q$  = flow rate (L/min),  $C$  = concentration (µg/L),  $dt$  = sample interval (min), and  $T$  = total event duration. The pollutant concentration in the sample volume collected into the single 9 L container directly represents the *EMC* for that event.

The total mass of pollutant ( $M$ ) was calculated as the product of the measured *EMC* and the total flow volume ( $V$ ) recorded. As explained earlier, the inflow and outflow runoff volumes are equal at the ditch check sites. Pollutant mass reduction efficiency (%) was calculated as:

$$M_R = \frac{(Mass_{IN} - Mass_{OUT})}{Mass_{IN}} \times 100 \quad (10)$$

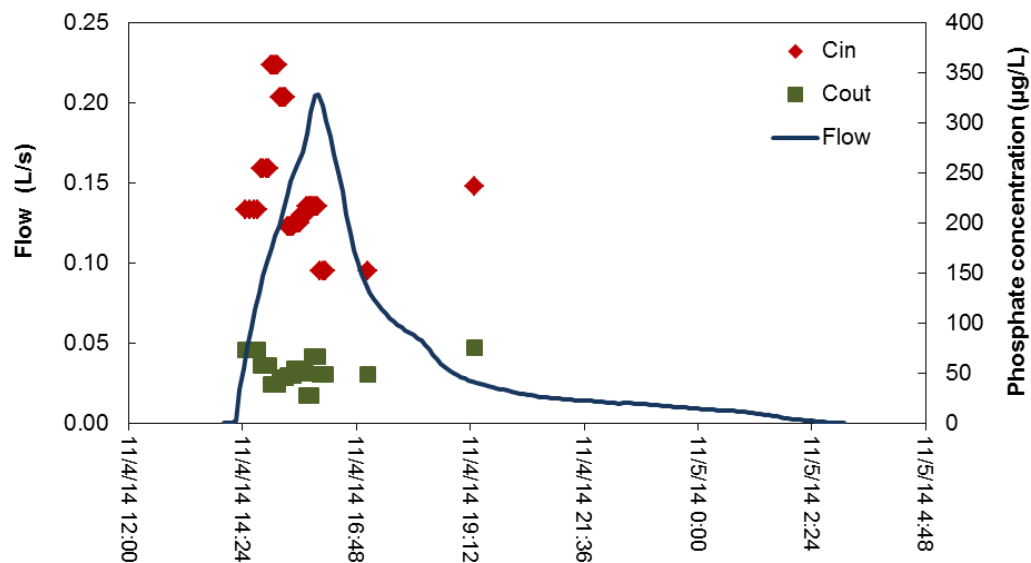
where,  $Mass_{IN}$  and  $Mass_{OUT}$  are the pollutant masses in inflow and outflow, respectively.

Probability exceedance plots (Erickson et al. 2013) for flow volumes and total pollutant mass loads were developed to assess the trends in the performance of the ditch check as a function of the flow volume exceedances. The influent and effluent pollutant mass load for the same event were paired and plotted as a function of the corresponding flow volume for all storm events monitored, and effectiveness of the ditch check in reducing the mass loads assessed for the exceedance volume.

### 3d. Results of Field Testing Using Synthetic Runoff

Because monitoring could not be performed due to lack of rainfall in Fall 2014, one synthetic runoff testing was conducted at each ditch check site in the MnDOT swales. The iron-enhanced ditch check site 2 was tested on November 4, 2014. Synthetic runoff was pumped into the swale at an average rate of 2.2 L/s (34 gal/min) over a period of two hours; the total volume input was 16 m<sup>3</sup> (4225 gallons). This is equivalent to 0.53 cm (0.21 inches) of rainfall over the total drainage area to the swales (0.30 ha or 0.74 ac) in 2 hours (rainfall intensity = 0.27 cm/hr or 0.11 in/hr). Flow and water quality data were collected until the entire synthetic runoff input completely drained through the ditch check, which was 15 hours from the introduction of runoff until the water level in the monitoring wells was less than 2 cm (0.8 inch).

The measured filter outflow and pollutant concentrations at the iron-enhanced ditch check site 2 are shown in Figure 13. Each data point represents the average phosphate concentration in 20 L of synthetic runoff volume passing through the ditch check. The event mean concentration (*EMC*) of phosphate for the entire test is 206 µg/L in the inflow and 45 µg/L in the outflow. The retention of phosphate in the iron-enhanced ditch check resulted in lower outflow phosphate concentrations. The total mass input and output are 0.41 g and 0.089 g, which corresponds to 78% mass reduction through the iron-enhanced ditch check. The zinc *EMC* were 70 µg/L inflow and 62 µg/L in outflow (concentration was measured in one composited sample). The zinc mass input of 0.14 g was reduced to 0.12 g, which corresponds to 11% retention of zinc mass by the ditch check.



**Figure 13. Results of synthetic runoff testing at the MnDOT iron-enhanced swale ditch check site 2, on Nov 4, 2014. Cin and Cout denote influent and effluent concentrations, respectively.**

The water truck testing at iron-enhanced ditch check site 1 was, however, not successful. In the first test, water was input at the rate of approximately 5 L/s (80 gal/min) and it was observed that the upstream and downstream water levels equalized when water depth reached approximately 15 cm (6 inches) upstream. The field testing could not be continued beyond this point, since there was no actual flow through the filter and water was likely by-passing treatment in the filter. Grab samples collected from the monitoring wells also supported this theory, since only a small reduction in phosphate levels was observed (283 µg/L in inflow and 200 µg/L in outflow). A second trial on November 6, with a lower water input rate of 3.5 L/s (55 gal/min), also resulted in a similar outcome, forcing the termination of field testing at this site. The performance of the iron-enhanced ditch check at site 1 could, thus, not be determined by field testing.

The issue of water pooling at site 1 suggests that problems related to the downstream slope at the site and/or the design and construction of the ditch check may exist. A flatter slope that prevents the outflow to be routed downstream may cause backup and pooling of water in the ditch check, affecting the downstream water head. The other possibility is the presence of an open spot within the filter bag arrangement where the inflow water is able to flow through without any resistance. If seeping between stacked filter bags occurs, water would fill up within the ditch check and produce the same water level on the upstream and downstream sides.

The water truck testing at the existing ditch check site 3 (base-case scenario) was conducted on November 6, 2014. The ditch was filled with 17 m<sup>3</sup> (4550 gallons) at a rate of 2.5 L/s (40 gal/min) for just under two hours. This corresponds to a rainfall depth of 0.79 cm (0.31 inch) over the total drainage area (0.22 ha or 0.54 ac) over two hours (i.e. rainfall intensity = 0.39 cm/hr or 0.16 in/hr). The water quality sampling duration was 12 hours (until entire input volume completely drained through the ditch check). The inflow and outflow composite samples collected contained 413 and 368 µg/L phosphate, respectively. This represents 11% reduction in the average concentration and total mass of phosphate input. However, it must be noted that the swale acted as source of phosphate. The water truck contained only 290 µg/L of phosphate, and the concentration increased as the water flowed through the swale, as evidenced by the measured inflow *EMC* of 413 µg/L. This is likely due to contribution of organic material or other detritus being degraded by bacteria in the swale. However, the existing ditch check provided very good zinc removal. The measured inflow and outflow zinc *EMCs* were 101 and 22 µg/L, respectively. The input zinc mass of 0.26 g was reduced to 0.06 g in the outflow, resulting in 78% reduction of zinc mass. The higher zinc removal can be attributed to adsorption of metal to organic matter in the top soil (Jang et al. 2005; LeFevre et al. 2015).

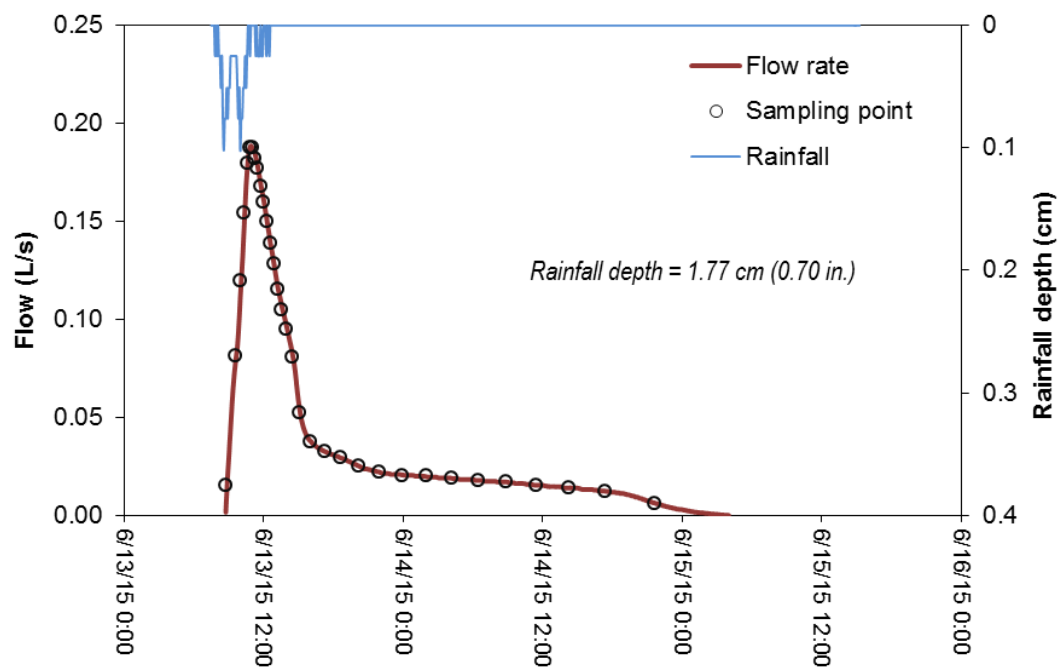
### **3e. Results of Field Monitoring During Rainfall Events**

Field monitoring at the MnDOT ditch check sites began in May 2015. The iron-enhanced ditch check (site 2) and the existing ditch check (site 3) were monitored for flow and water



quality during rainfall events from May through August 2015. Totally, 19 events were monitored at the iron-enhanced ditch check (site 2). After combining data with overlapping flows from two rainfall events (as described in the ‘data analysis’ section), the number of sampling events is 17 at the iron-enhanced ditch check. Thirteen events were monitored at the existing ditch check (site 3); fewer events were sampled since smaller rainfall events did not generate runoff due to infiltration in the swale, which is wider than the swale at site 2. Because of different rainfall-runoff patterns at the two swales, and three separate instances of equipment malfunction at site 2 (displacement of ISCO sampler tubing which was fixed promptly), the sampling dates at the two sites are different on some occasions.

The events monitored at both sites had rainfall depths ranging from 0.76 to 10.7 cm (0.30 to 4.23 inches), and total rainfall durations between 0.75 and 28 hours. A sample hydrograph showing the recorded flow through the iron-enhanced ditch check during a water quality event is shown in Figure 14 as an example. Distribution of the water sample collection during the storm course is indicated in the plot. The same method was followed for the existing ditch check site (sample figure is thus not shown).



**Figure 14. Sample hydrograph recorded at the MnDOT iron-enhanced ditch check site 2 on June 14, 2015, rainfall event. The composite sampling regime is also shown in the plot.**

The iron-enhanced ditch check site 1 could not be monitored because of flow routing issues at the site. For the two storms monitored, the upstream and downstream water levels at the ditch

check became similar within a short time after rainfall commenced and remained so until runoff inflows began to cease. The upstream water appeared to drain faster and the downstream water level decreased much more gradually. As a result, there was no flow through the filter (zero flow when water level measurements are equal, and negative flow when downstream level is higher than the upstream level), and hence water samples were not taken during the storm. Similar observations had been made during the Fall 2014 water truck tests as well. The possible explanation for this behavior is that the inflow runoff is flowing backwards, infiltrating faster into the swale, and/or flowing around the edges of the filter, although a small portion of the runoff might be flowing through the filter. Therefore, site 1 monitoring was not continued.

The total rainfall depth and duration, total flow volume, pollutant *EMCs*, pollutant mass, and pollutant removals at the MnDOT iron-enhanced ditch check and existing ditch check sites are provided in Table 4 through Table 7 (also provided in Appendix D). Since the inflow and outflow volumes are equal, the percent *EMC* reductions will be the same value as the percent pollutant mass reductions provided in Table 5 and Table 7. If flow and water quality data from two overlapping storm events were combined and the net performance computed (as described in ‘data analysis’ section), such events have been marked in the tables.

The rain gauge did not record the rainfall depth during four rainfall events since it was clogged by debris. For these events, the rainfall data were obtained from a weather station located about 6.8 km (4.2 miles) from the swale sites, which can be accessed at the website <http://www.wunderground.com/cgi-bin/findweather/getForecast?query=K21D>. The rainfall depths recorded at the MnDOT swales and at the weather station were similar for 15 other events (linear correlation  $R^2 = 0.9603$ ). Rainfall depths referenced from the weather station have been marked in the monitoring data summary tables.

**Table 4. Water quality monitoring data for the Iron-Enhanced Ditch Check (Site 2) in MnDOT swales: *EMCs* of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd).**

Event Date	Rainfall depth (cm)	Rainfall duration (hr)	Flow volume (L)	SRP EMC <sub>IN</sub> (µg/L)	SRP EMC <sub>OUT</sub> (µg/L)	Cu EMC <sub>IN</sub> (µg/L)	Cu EMC <sub>OUT</sub> (µg/L)	Pb EMC <sub>IN</sub> (µg/L)	Pb EMC <sub>OUT</sub> (µg/L)	Zn EMC <sub>IN</sub> (µg/L)	Zn EMC <sub>OUT</sub> (µg/L)	Cd EMC <sub>IN</sub> (µg/L)	Cd EMC <sub>OUT</sub> (µg/L)
05/03/15	1.13	7.92	2687	666	352	23.1	33.6	0.528	2.16	18.6	39.8	0.0763	0.0987
05/10/15	0.91 <sup>†</sup>	n/a	2781	885	504	103	68.0	0.535	1.12	28.0	30.1	0.0953	0.0647
05/14/15	1.14 <sup>†</sup>	n/a	2968	627	401	68.3	62.4	0.942	1.10	16.5	23.1	0.0517	0.0680
05/17/15	1.02 <sup>†</sup>	n/a	3455	561	302	72.4	90.8	1.24	1.97	24.9	59.1	0.2643	0.0517
05/24/15*	3.14 (1.98, 1.15)	20.4, 9.25	8806	1000	461	67.5	72.2	1.12	1.27	13.9	30.3	0.0237	0.0303
05/29/15	1.59	19.3	4424	417	228	80.9	82.3	3.69	6.08	25.3	53.1	0.1397	0.0543
06/03/15	1.90	13.5	4357	280	179	30.1	70.9	0.602	1.30	24.7	26.3	0.0410	0.0403
06/11/15	1.08	10.8	2000	457	328	42.8	69.7	0.516	1.32	77.3	98.6	0.0507	0.0373
06/13/15	1.77	4.75	4804	168	98	71.1	70.6	1.28	1.45	29.5	35.6	0.0257	0.0153
06/17/15*	2.54 (1.32, 1.22)	3.83, 2.67	9013	114	74	38.3	52.4	0.940	1.03	24.8	24.7	0.0173	0.0127
06/22/15	1.24	2.83	3304	128	81	16.9	69.3	0.478	1.55	30.5	33.5	0.0587	0.0400
06/28/15	0.76	1.83	1301	283	241	66.0	71.7	1.43	1.19	24.2	36.1	0.0560	0.0357
06/29/15	1.88	0.75	4211	116	69	9.75	59.6	0.546	1.39	12.7	43.8	0.0270	0.0283
07/06/15*	10.7	12.7	17593	218	241	10.6	9.23	0.490	0.217	15.8	14.3	0.0166	0.0129
07/28/15	0.79	2.17	1501	202	115	10.1	59.3	0.891	1.23	15.6	113	0.0250	0.0247
08/18/15	3.54	27.9	5206	274	175	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	4.11	5.42	7446	184	200	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

<sup>†</sup> Rainfall depth from the nearby weather station.

n/a Data not available.

\*Data combined for two events and represents net performance for two combined sampling events.

**Table 5. Water quality monitoring data for the Iron-Enhanced Ditch Check (Site 2) in MnDOT swales: Total mass in ( $M_{IN}$ ), mass out ( $M_{OUT}$ ) and mass removal ( $M_R$ ) of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd).**

Event Date	SRP $M_{IN}$ (g)	SRP $M_{OUT}$ (g)	SRP $M_R$ (%)	Cu $M_{IN}$ (mg)	Cu $M_{OUT}$ (mg)	Cu $M_R$ (%)	Pb $M_{IN}$ (mg)	Pb $M_{OUT}$ (mg)	Pb $M_R$ (%)	Zn $M_{IN}$ (mg)	Zn $M_{OUT}$ (mg)	Zn $M_R$ (%)	Cd $M_{IN}$ (mg)	Cd $M_{OUT}$ (mg)	Cd $M_R$ (%)
05/03/15	1.20	0.63	47.1	62.2	90.3	-45.2	1.42	5.80	-309	50.1	107	-114	0.205	0.265	-29.3
05/10/15	0.62	0.35	43.1	287	189	34.1	1.49	3.12	-110	77.8	83.7	-7.65	0.265	0.180	32.2
05/14/15	1.37	0.87	36.0	203	185	8.72	2.79	3.27	-17.1	48.9	68.6	-40.3	0.153	0.202	-31.6
05/17/15	1.94	1.04	46.2	250	314	-25.5	4.29	6.80	-58.6	86.0	204	-138	0.913	0.178	80.5
05/24/15*	8.81	4.06	53.9	595	636	-6.91	9.83	11.2	-13.5	123	267	-118	0.208	0.267	-28.2
05/29/15	1.84	1.01	45.3	358	364	-1.71	16.3	26.9	-65.0	112	235	-110	0.618	0.240	61.1
06/03/15	1.22	0.78	36.1	131	309	-136	2.62	5.65	-116	107	115	-6.61	0.179	0.176	1.63
06/11/15	0.91	0.66	28.2	85.6	139	-62.9	1.03	2.64	-156	155	197	-27.6	0.101	0.0747	26.3
06/13/15	0.81	0.47	41.7	341	339	0.68	6.16	6.98	-13.3	142	171	-20.8	0.123	0.0737	40.3
06/17/15*	1.03	0.66	35.4	345	472	-37.0	8.47	9.32	-10.0	224	223	0.39	0.156	0.114	26.9
06/22/15	0.42	0.27	36.6	56.0	229	-309	1.58	5.11	-223	101	111	-9.92	0.194	0.132	31.8
06/28/15	0.37	0.31	14.9	85.9	93.2	-8.53	1.85	1.55	16.5	31.5	47.0	0.00	0.0728	0.0464	36.3
06/29/15	0.49	0.29	40	41.0	251	-511	2.30	5.85	-154	53.3	184	-246	0.114	0.119	-4.94
07/06/15*	3.84	4.24	-10.5	186	162	12.8	8.61	3.81	55.8	279	251	10.0	0.293	0.227	22.3
07/28/15	0.30	0.17	43.1	15.1	89.1	-488	1.34	1.85	-38.2	23.4	169	-624	0.038	0.037	1.33
08/18/15	1.42	0.91	36.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	1.37	1.49	-8.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

\* Data represents net performance for two combined sampling events.

**Table 6. Water quality monitoring data for the Existing Ditch Check (Site 3) in MnDOT swales: *EMCs* of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd).**

Event Date	Rainfall depth (cm)	Rainfall duration (hr)	Flow volume (L)	Phosphate EMC <sub>IN</sub> (µg/L)	Phosphate EMC <sub>OUT</sub> (µg/L)	Cu EMC <sub>IN</sub> (µg/L)	Cu EMC <sub>OUT</sub> (µg/L)	Pb EMC <sub>IN</sub> (µg/L)	Pb EMC <sub>OUT</sub> (µg/L)	Zn EMC <sub>IN</sub> (µg/L)	Zn EMC <sub>OUT</sub> (µg/L)	Cd EMC <sub>IN</sub> (µg/L)	Cd EMC <sub>OUT</sub> (µg/L)
05/14/15	1.14 <sup>†</sup>	n/a	1429	486	631	19.9	28.6	1.90	1.13	43.2	25.8	0.0777	0.0590
05/29/15	1.59	19.3	1000	290	292	19.9	12.4	3.91	3.86	66.9	111	0.0403	0.0303
06/03/15	1.90	13.5	2906	342	370	9.49	9.49	0.95	0.470	17.64	8.01	0.0223	0.0157
06/07/15	2.13 <sup>†</sup>	n/a	9884	143	428	5.75	9.36	0.38	0.315	7.32	5.99	0.0140	0.0260
06/13/15	1.77	4.75	12641	232	195	39.1	24.7	1.34	0.611	15.8	10.1	0.0263	0.0247
06/20/15	1.22	2.67	1650	57.2	160	6.30	11.6	0.479	0.603	25.4	22.0	0.0387	0.0270
06/22/15	1.24	2.83	4807	144	301	55.9	14.3	0.798	1.32	18.1	15.0	0.0367	0.0477
06/29/15	1.88	0.75	7230	181	176	4.80	7.30	0.360	0.784	8.62	5.13	0.0067	0.0137
07/06/15*	10.7	12.7	25181	416	357	52.0	33.5	1.18	0.754	105	25.0	0.0629	0.0111
07/12/15	6.25	8.08	9022	121	166	4.13	6.43	0.224	0.429	4.37	5.31	0.0160	0.0383
07/18/15	2.36	2.08	2004	169	151	8.99	49.6	0.380	1.095	44.2	4.47	0.0113	0.0113
08/18/15	3.54	27.8	600	38	79	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	4.11	5.42	9773	244	380	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

<sup>†</sup> Rainfall depth from the nearby weather station.

n/a Data not available.

\* Data represents net performance for two combined sampling events.

**Table 7. Water quality monitoring data for the Existing Ditch Check (Site 3) in MnDOT swales: Total mass in ( $M_{IN}$ ), mass out ( $M_{OUT}$ ) and mass removal ( $M_R$ ) of phosphate (SRP), dissolved copper (Cu), dissolved lead (Pb), dissolved zinc (Zn), and dissolved cadmium (Cd).**

Event Date	SRP $M_{IN}$ (g)	SRP $M_{OUT}$ (g)	SRP $M_R$ (%)	Cu $M_{IN}$ (mg)	Cu $M_{OUT}$ (mg)	Cu $M_R$ (%)	Pb $M_{IN}$ (mg)	Pb $M_{OUT}$ (mg)	Pb $M_R$ (%)	Zn $M_{IN}$ (mg)	Zn $M_{OUT}$ (mg)	Zn $M_R$ (%)	Cd $M_{IN}$ (mg)	Cd $M_{OUT}$ (mg)	Cd $M_R$ (%)
05/14/15	0.69	0.90	-29.8	28.5	40.8	-43	2.72	1.62	40.5	61.8	36.9	40.3	0.111	0.084	24.0
05/29/15	0.29	0.29	-0.7	19.9	12.4	38	3.91	3.86	1.28	66.9	111	-65.5	0.040	0.030	24.8
06/03/15	0.99	1.08	-8	27.6	27.6	0.0	2.77	1.37	50.8	51.3	23.3	54.6	0.065	0.046	29.9
06/07/15	1.41	4	-199	56.9	92.5	-63	3.78	3.11	17.6	72.3	59.2	18.2	0.138	0.257	-85.7
06/13/15	2.93	2.46	16	495	312	37	17.0	7.73	54.4	199	128	35.8	0.333	0.312	6.3
06/20/15	0.09	0.26	-180	10.4	19.1	-83	0.79	1.00	-26.0	41.9	36.3	13.4	0.064	0.045	30.2
06/22/15	0.69	1.44	-109	269	68.7	74	3.83	6.37	-66.1	86.9	72.1	17.1	0.176	0.229	-30.0
06/29/15	1.30	1.27	2	34.7	52.7	-52	2.60	5.67	-118	62.3	37.1	40.4	0.048	0.099	-105
07/06/15*	10.49	8.99	14	1310	843	36	29.6	19.0	35.8	2632	630	76.1	1.583	0.278	82.4
07/12/15	1.09	1.50	-37	37.3	58.0	-55	2.02	3.87	-91.8	39.5	47.9	-21.3	0.144	0.346	-140
07/18/15	0.34	0.30	11	18.0	99.42	-452	0.761	2.19	-188	88.6	8.95	89.9	0.023	0.023	0.0
08/18/15	0.02	0.05	-111	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	2.39	3.71	-55	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

\* Data represents net performance for two combined sampling events.

n/a Data not available

### *i. Iron-Enhanced Ditch Check Performance*

The runoff flow volumes measured at the iron-enhanced ditch check correlated well with the rainfall depths (linear  $R^2 = 0.901$ ). The water quality at the iron-enhanced ditch check during 17 storm events sampled is summarized in Table 4 and Table 5. While the influent phosphate *EMCs* ranged between 114 and 1000  $\mu\text{g/L}$  (mean = 386  $\mu\text{g/L}$ ; median = 280  $\mu\text{g/L}$ ), the effluent *EMCs* ranged between 69 and 504  $\mu\text{g/L}$  (mean = 238  $\mu\text{g/L}$ ; median = 228  $\mu\text{g/L}$ ), suggesting that phosphate was generally retained by the iron-enhanced ditch check. However, the effluent *EMCs* exceeded the 100  $\mu\text{g/L}$  phosphate water quality criterion (North Central Hardwood Forest) in 13 out of 17 events.

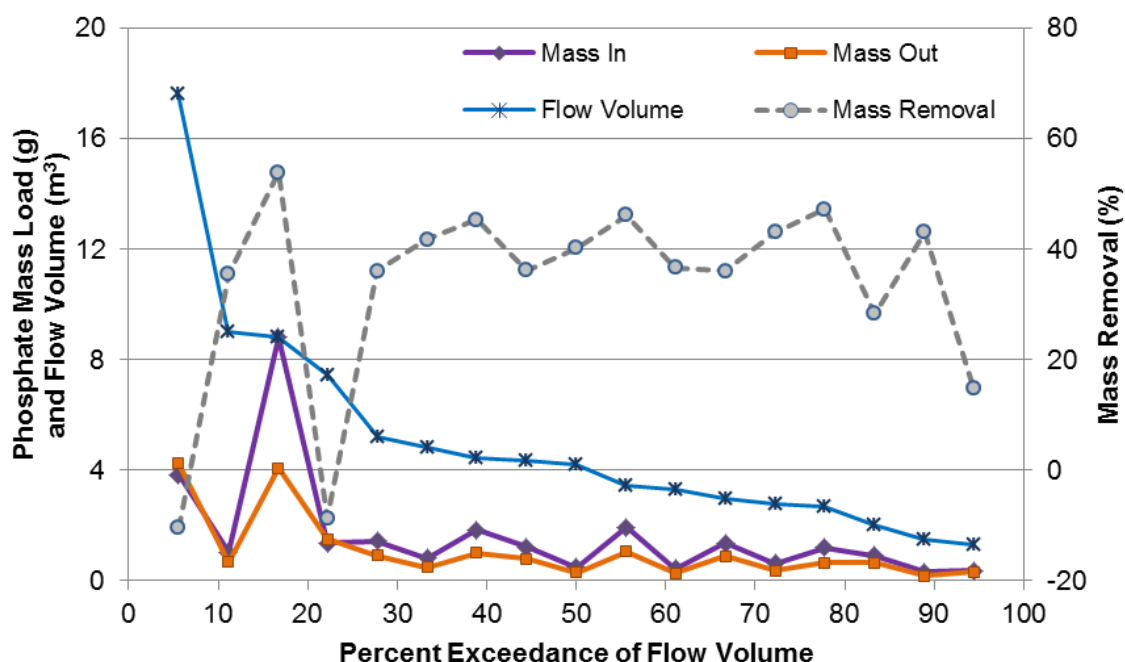
The phosphate mass reductions ranged between 15 and 54% during 15 sample events (mean = 39%; median = 40%). The remaining two events were exceptions to positive removal: the largest event sampled on July 6, 2015, that recorded a total rainfall depth of 10.4 cm (4.2 inches in 13 hours), which is a one-year historical event for Minnesota, and the high-intensity event on August 22, 2015, (4.1 cm or 1.6 inches in 5.4 hours). The effluent *EMCs* were higher than that of the influent resulting in net mass removal of (-11)% and (-9)% for these two events. During the July 6 extreme event, the upstream water level was at the top of the ditch check. The higher magnitude flows most likely overwhelmed the ditch check and resulted in poor pollutant removal due to much shorter contact time available for pollutant retention or perhaps due to by-passing treatment as well.

The mean and median mass removals for all 17 events sampled were 33% and 37%, respectively. The cumulative phosphate mass input and output during the 17 events were 28 g and 18.2 g, respectively, which is almost 35% mass reduction for the entire monitoring duration. The phosphate reductions observed during storm events was lower in comparison to reductions for the one field test conducted in 2014. This could be because storm flows are unsteady and the pollutant characteristics and distribution of mass load varies over the storm course, which can result in variable performance of the iron-enhanced ditch check.

One observation made over the monitoring duration was that the influent phosphate *EMC* decreased from May through August 2015. One possible reason for the high phosphate concentration during the early spring storm events is wash-off of phosphorus accumulated over winter. It is also possible that the compost in the top soil layer on the ditch check could have leached into the influent runoff and increased its overall phosphorus concentration. However, the iron-enhanced ditch check provided removal of the input phosphate during most rainfall events.

A probability exceedance plot for the flow volumes measured during 17 events at the iron-enhanced ditch check is shown in Figure 15. The paired influent and effluent phosphate mass loads for each storm event are plotted as a function of the percent volume exceedance. The corresponding mass removal efficiency is also plotted. Four events producing 25% exceedance

of flow volumes ( $> 7000$  L) contributed variable phosphate mass load inputs. The corresponding mass load reductions were also mixed, with the highest flow volume producing negative mass removal and the next two flow volume magnitudes showed high load reductions. The influent phosphate mass was consistently removed for flow volumes less than 5000 L. The total mass load input from the 25% exceedance of flow volumes was greater than the combined load from flow volumes that have more than 25% exceedance probability (15 g vs 12.9 g). Based on the exceedance plot, the iron-enhanced ditch check can be expected to provide phosphate mass reductions when runoff volumes are less than 5000 L. Above 5000 L flow volumes, removal of phosphate could be mixed depending on the rainfall characteristics. For example, low versus high-intensity rainfall events determine the rate of runoff volume loading to the ditch check and influence the associated pollutant mass load distribution, and hence the overall mass reduction achievable through the iron-enhanced ditch check.



**Figure 15. Exceedance plot for flow volume and corresponding paired phosphate mass loads and mass load reductions at the iron-enhanced ditch check constructed in the MnDOT swales.**

Metal reduction performance of the ditch check was determined for 15 events (the last two storm events monitored in August were not analyzed for metals). The overall metal removal performance of the iron-enhanced ditch check is summarized in Table 8. Runoff to the iron-enhanced ditch check contained median dissolved metal concentrations of 43  $\mu\text{g/L}$  Cu, 0.89



µg/L Pb, 25 µg/L Zn, and 0.051 µg/L Cd (*EMCs*). Except copper, the observed concentrations are generally lower than the typical median concentration of dissolved metals in runoff from freeways: 11 µg/L Cu, 1.8 µg/L Pb, 51 µg/L Zn, and 0.68 µg/L Cd (Maestre and Pitt 2005). However, the effluent metal *EMCs* were higher than that of the influent *EMCs* for most events. Also, the effluent copper *EMCs* often exceeded the MPCA's water quality criterion for aquatic life and recreation waters. The Zn and Pb *EMCs* were higher than the threshold value for one storm only. While the mean concentration and mass loads of Cu, Pb, and Zn were reduced during two events only, removal of Cd was observed during 13 events. It must be noted that some of the large negative mass removals observed were for relatively very low concentrations of metals, especially for lead and cadmium. No particular trend associated with respect to flow volume or rainfall depth was visible for the observed removal patterns.

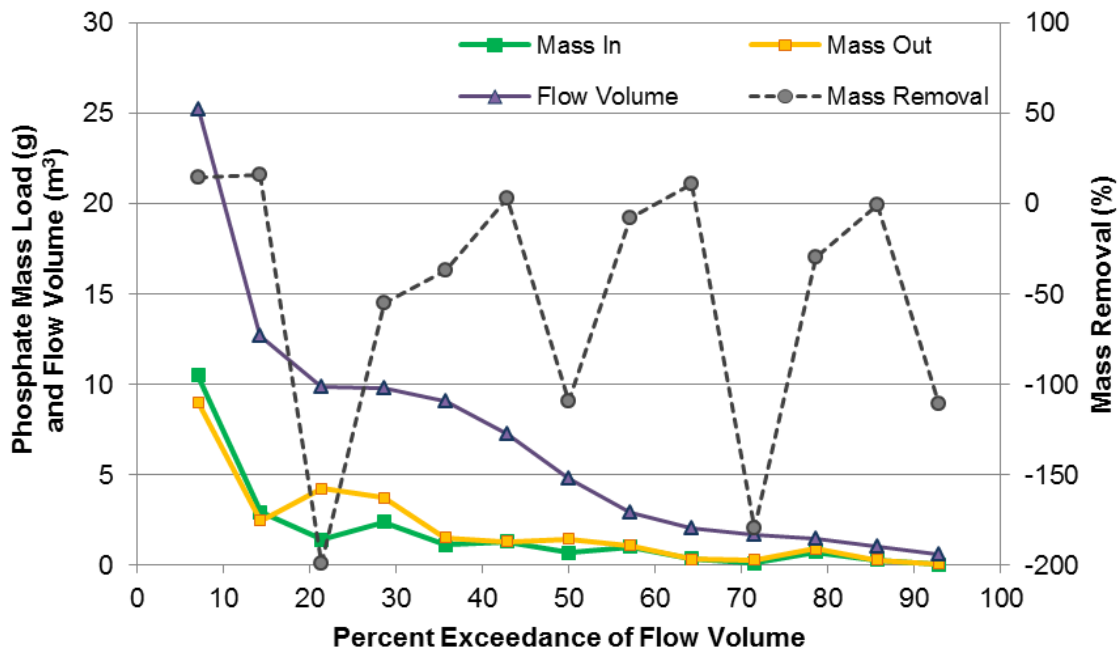
**Table 8. Summary of dissolved metal *EMCs* and mass loads at the iron-enhanced ditch check (site 2) in the MnDOT swales monitored for 15 storm events.**

Performance Measure		Copper		Lead		Zinc		Cadmium	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
<b><i>EMC</i></b> <b>(µg/L)</b>	<i>Range</i>	9.75 – 103	9.23 – 90.8	0.48 – 3.69	0.22 – 6.08	12.7 – 77.3	14.3 – 113	0.0167 – 0.264	0.0127 – 0.0987
	<i>Mean</i>	47.4	62.8	1.01	1.63	25.5	44.1	0.0646	0.0410
	<i>Median</i>	42.8	69.3	0.891	1.30	24.7	35.6	0.0507	0.0373
<b>Mass Load</b> <b>(mg)</b>	<i>Range</i>	15.1 – 595	89.1 – 636	1.03 – 16.3	1.55 – 26.9	23.4 – 279	47 – 267	0.038 – 0.913	0.037 – 0.267
	<i>Mean</i>	203	257	4.67	6.65	107	162	0.242	0.156
	<i>Median</i>	186	229	2.62	5.65	101	171	0.179	0.176
<b>Mass Removal</b> <b>(%)</b>	<i>Range</i>	(-511) – 34.1		(-309) – 55.8		(-624) – 10		(-31.6) – 80.5	
	<i>Mean</i>	-105		-80.7		-27.6		17.8	
	<i>Median</i>	-25.5		-58.6		-96.7		26.3	

Based on Table 8, it can be summarized that the iron-enhanced ditch check filter was generally unable to retain the dissolved metals in runoff. The average metal concentrations were in fact increased through the iron-enhanced ditch check, which could be because of leaching of metals from the filter media itself and/or from the metal frame enclosure built around the filter media. The water truck test also showed very low positive removal of zinc from the synthetic runoff. Overall, the iron-enhanced ditch check did not perform well for metals.

## ii. Existing (Unmodified) Ditch Check Performance

The existing ditch check generally showed very low or no retention of phosphates in runoff, as expected (Table 6 and Table 7). For the 13 events sampled, the influent phosphate *EMCs* were between 38 and 554  $\mu\text{g/L}$  (mean = 220  $\mu\text{g/L}$ ; median = 181  $\mu\text{g/L}$ ) and the effluent *EMCs* ranged between 79 and 631  $\mu\text{g/L}$  (mean = 284  $\mu\text{g/L}$ ; median = 292  $\mu\text{g/L}$ ) at this site. The phosphate mass removals measured ranged between -199% and 16% (mean = -53%; median = -30%), confirming the poor phosphate retention ability of ditch checks that do not contain specialized treatment media. The cumulative phosphate mass input and output were 22.7 g and 26.5 g, respectively, which means no net removal and 14% export of phosphate occurred at this site. This is confirmed by the flow volume exceedance plot (Figure 16); the influent mass load line is higher than the effluent line for flow volumes < 9880 L, which is greater than 25% exceedance flow volume at this site. A low phosphate removal occurred for <25% exceedance flow volumes. These two trends are contrary to the iron-enhanced ditch check performance.



**Figure 16. Exceedance plot for flow volume and corresponding paired phosphate mass loads and mass load reductions at the existing ditch check in MnDOT swales.**

The range, mean, and median of metal *EMCs*, mass loads, and mass removals at the existing ditch check during 11 monitored events are summarized in Table 9. The concentrations of dissolved metals in the influent were generally low when compared to typical highway runoff concentrations (Maestre and Pitt 2005). Dissolved zinc mass loads were reduced during most

events, for an average 36% reduction. Reductions of Cu, Pb, and Cd mass loads were mixed, with positive removal observed during 5 or 6 events out of 11 monitored events. The synthetic runoff tests conducted in Fall 2014 also showed the good reduction of zinc mass load through the ditch check. The effluent copper *EMCs* exceeded the MPCA's water quality criteria for metals during several events, while exceedances of zinc, lead, and cadmium occurred during a few events only.

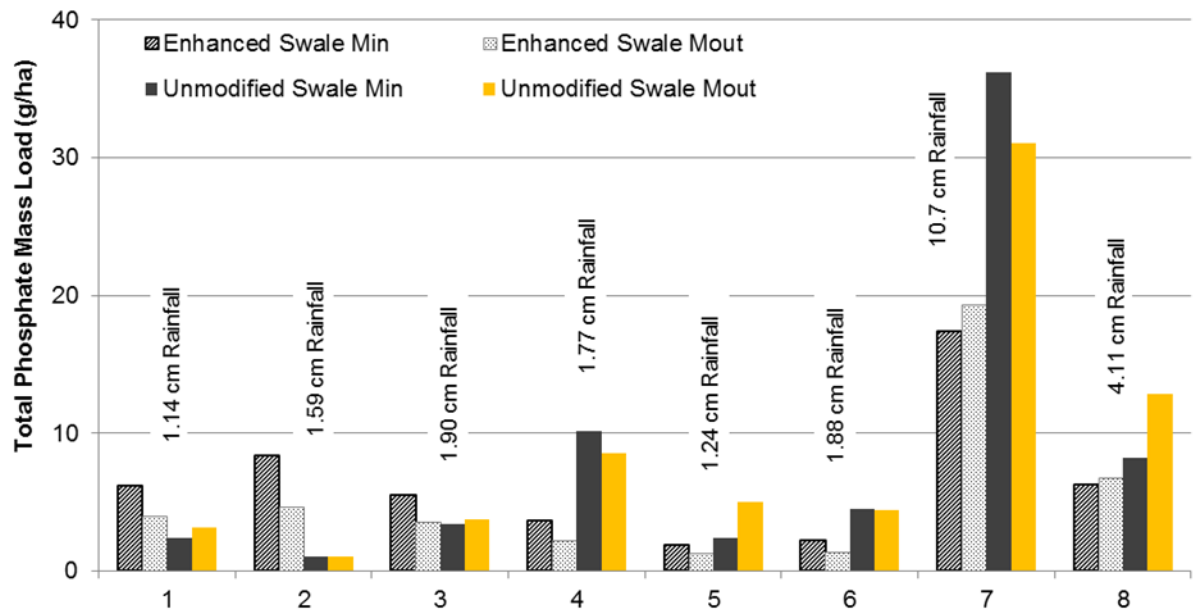
**Table 9. Summary of dissolved metal *EMCs* and mass loads at the existing ditch check (site 3) in the MnDOT swales monitored for 11 storm events.**

Performance Measure		Copper		Lead		Zinc		Cadmium	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
<b><i>EMC</i></b> <b>(µg/L)</b>	<i>Range</i>	4.13 – 55.9	6.43 – 49.6	0.224 – 3.91	0.315 – 3.86	4.37 – 105	4.47 – 111	0.0067 – 0.078	0.0111 – 0.059
	<i>Mean</i>	20.6	18.8	1.08	1.03	32.4	21.6	0.032	0.028
	<i>Median</i>	9.49	12.4	0.798	0.754	18.1	10.1	0.026	0.026
<b>Mass Load</b> <b>(mg)</b>	<i>Range</i>	10.4 – 1310	12.4 – 843	0.761 – 29.6	1.00 – 19.0	39.5 – 2632	8.95 – 630	0.023 – 1.58	0.023 – 0.346
	<i>Mean</i>	210	148	6.34	5.07	309	108	0.248	0.159
	<i>Median</i>	34.7	58.0	2.77	3.86	66.9	47.9	0.111	0.099
<b>Mass Removal</b> <b>(%)</b>	<i>Range</i>	(-452) – 74.4		(-188) – 54		(-65.5) – 89.9		(-140) – 82.4	
	<i>Mean</i>	-51.3		-26.3		27.2		14.8	
	<i>Median</i>	-43.3		1.28		35.8		6.33	

Overall, the dissolved metal mass load reductions observed at the existing un-modified swale were higher than that at the iron-enhanced ditch check. This is in agreement with the synthetic runoff test observations. The organic matter in the soil berm of the un-modified ditch check appears to have better metal-adsorption abilities when compared to the iron-enhanced sand media without organic matter.

Comparison of the phosphate mass load characteristics at the iron-enhanced ditch check and existing (un-modified) ditch check (base-case scenario) was done for the eight storm events common to both sites. The total phosphate mass loads were normalized by the respective drainage areas to the ditch checks (0.29 ha for iron-enhanced ditch check, and 0.22 ha for existing ditch check). In general, the phosphate mass load inputs to the existing ditch check were higher than the iron-enhanced swale for the same amount of rainfall. The existing swale exported phosphate mass loads during majority of the storms. On the other hand, the iron-

enhanced swale was much more effective in retaining the runoff phosphate mass inputs, except during the largest storms.



**Figure 17. Comparison of phosphate mass loadings at the enhanced ditch check and existing ditch check in the MnDOT swales for eight storm events monitored in 2015. The rainfall depths for each event is indicated.**

Thus, it can be concluded that the iron-enhanced check dam sections are largely effective in reducing phosphate mass loads, and mean reductions of 35% can be expected. No net removal occurs through the swales that do not contain specialized ditch checks. In the case of dissolved metals, the existing ditch check performed better than the iron-enhanced section of the ditch check, probably due to the presence of organic compounds in the soil placed over the ditch check. The MnDOT check dam design, if an iron-enhanced filter section were placed in the middle of the check dam, would incorporate the best of each result, where the current check dam design has a positive retention of metals and the iron-enhanced section has a positive retention of phosphate.

#### 4. Iron-Enhanced Ditch Checks for City of Roseville Swales

##### 4a. Site Description

Swales located along Twin Lakes Parkway in Roseville were selected for the installation of iron-enhanced ditch check (Figure 18). The swales on the east and west side of the Parkway are part of the infiltration-stormwater reuse-irrigation system design employed at this location, under the right-of-way of the City of Roseville. The swales are divided into individual basins

that are interconnected via an underdrain pipe, and each swale basin also has a catch basin to receive runoff directly from the adjoining roadway. Runoff passing through the east- and west-side swales finally drains into a single storm drain located at the end of the Parkway. A unique feature in the swale basins is the concrete weir wall that holds a steel plate weir (Figure 18b). This feature formed the basis for developing the iron-enhanced ditch check design for the Roseville swales.



**Figure 18. (a) Map location and (b) Photograph of the Roseville swale basins along Twin Lakes Parkway, Roseville, MN (Note: Photograph does not show the location of iron-enhanced ditch check installed later).**



The last swale basin on the east side of the Parkway was selected as the site for the iron-enhanced ditch check installation. The ease of access to the underdrain at this location was the primary reason for selecting this location for field testing purpose. The iron-enhanced ditch check was developed as an “insert”, taking into consideration the unique weir feature on site. The size of the test swale basin, measured from the upstream end to the weir location, is 11 m x 3.4 m (37 ft x 11 ft). The computed upstream volume of the basin is 16 m<sup>3</sup> (568 ft<sup>3</sup>), assuming uniform average basin depth of 0.43 m (1.4 ft). The drainage area to the test basin is not known since the basin receives runoff directly from the roadway as well as from the swale basins upstream via the underdrain.

#### **4b. Design and Installation of Roseville Ditch Check**

The MnDOT ditch check design was adapted to suit the Roseville swale site. The ditch check was designed such that the filter media can be contained within a frame enclosure that can be inserted into the existing concrete wall. The filter was sized 1.8 m x 0.15 m x 0.46 m (6 ft x 0.5 ft x 1.5 ft) (length x width x height) to fit the opening in the concrete weir wall. As proposed in the preliminary design, it was planned to place the sand-iron media in geotextile filter bags that can be stacked inside the frame. A brief description of the Roseville ditch check is provided in the section. Detailed description of the materials and installation of the Roseville ditch check are provided in Appendix A.

An aluminum filter frame enclosure was designed and constructed at SAFL. The frame was equipped with a key for fitting the frame into the notch in the concrete wall. The filter media, composed of 92.5% sand and 7.5% iron B (by weight), was mixed in a mortar mixer at SAFL. The media was filled into the geotextile filter bags. Two sets of 7.6 cm (3 inch) diameter filter bags were made; one set was 0.61 m (2 ft) long, and the second was 0.91 m (3 ft) long. Different lengths were chosen to achieve good packing and overlap of filter media in the frame enclosure.

The ditch check was installed by the project personnel from University of Minnesota in September 2014. The existing steel weir was removed by the City of Roseville personnel prior to filter installation. First, the aluminum frame enclosure was installed in the concrete wall. The sides and bottom of the enclosure were made water-tight by applying a silicone-based sealant. The sealant was allowed to completely dry before installing the filter bags. After placing a sheet of geotextile fabric covering the interior of the frame enclosure (i.e. like a wrap sheet), the filter bags were packed inside the enclosure. Loose filter media was placed over each bag layer and filled in the gaps around the bags. Once the enclosure was full, the geotextile wrap fabric was folded over from the top and sealed to complete the filter assembly. The final dimension of the filter was 1.8 m L x 0.15 m W x 0.46 m H (6 ft x 0.5 ft x 1.5 ft). Photograph of the Roseville iron-enhanced ditch check is shown in Figure 19.



**Figure 19. Iron-enhanced ditch check installed at the Roseville swale basin.**

As will be discussed later, water was observed to leak from one corner of the ditch check during field testing. Therefore, the ditch check was re-installed in July 2015 so that further tests could be conducted. In the new installation, the filter media was placed inside a single geotextile bag. The revision eliminated the multiple bag-design previously adopted. The filter media packed in the old individual bags was taken out and poured into a single geotextile bag inside the frame enclosure, and sealed at the top. Given the small size of the ditch check, the single-bag design is better as it reduces the amount of geotextile material needed. The final dimensions and appearance of the new ditch check filter were same as the first installation (photograph is provided in Appendix A).

#### **4c. Field Testing Method**

It was planned to determine the performance of the Roseville ditch check through field testing using synthetic runoff. A 7571 L (2000 gallon) -capacity water truck was used for the tests. The truck water was dosed with measured amounts of phosphorus and zinc to achieve a certain target concentration in the synthetic runoff; the target concentration was different for each test but was largely based on typical median pollutant concentration in urban runoff (Maestre and Pitt 2005). A hose with valve control was attached to the water truck spout to deliver the runoff. Water was introduced at the entrance of the swale basin, close to the catch basin (Figure 20). The quantity of water delivered into the basin was tracked throughout the test using a water meter attached to hose end. The water meter readings were taken every 5 or 10 minutes. The underdrain in the swale basin remained plugged throughout the test.



**Figure 20. Photograph showing the water truck testing conducted at the Roseville iron-enhanced ditch check site on 28 Oct, 2014.**

A U-shaped aluminum channel was attached at the bottom on the downstream face of the frame at the time of filter installation. The purpose of this channel was to serve as a “gutter” that collects the outflow from the filter. The discharge from the gutter was collected in a bucket, and the volume of water collected over the recorded time measured to calculate the outflow rate. The flow measurements were made every 10 or 15 minutes. The upstream water level at the ditch check was also measured every 5 or 10 minutes.

Inflow water samples were collected immediately upstream of the ditch check, instead of sampling directly from the truck. This was done because the swale basin consists of engineered soil with mulch as a constituent, which can contribute phosphorus to the water flowing through the swale [This was confirmed during a mock test conducted on August 26, 2014; concentration of phosphate in the underdrain outflow was much higher ( $172 \mu\text{g/L}$ ) than the input water ( $\sim 1 \mu\text{g/L}$ )]. Outflow water samples were collected directly from the gutter. The water sampling was done at 10 or 15 minute intervals such that 8-12 samples were collected during the test duration.



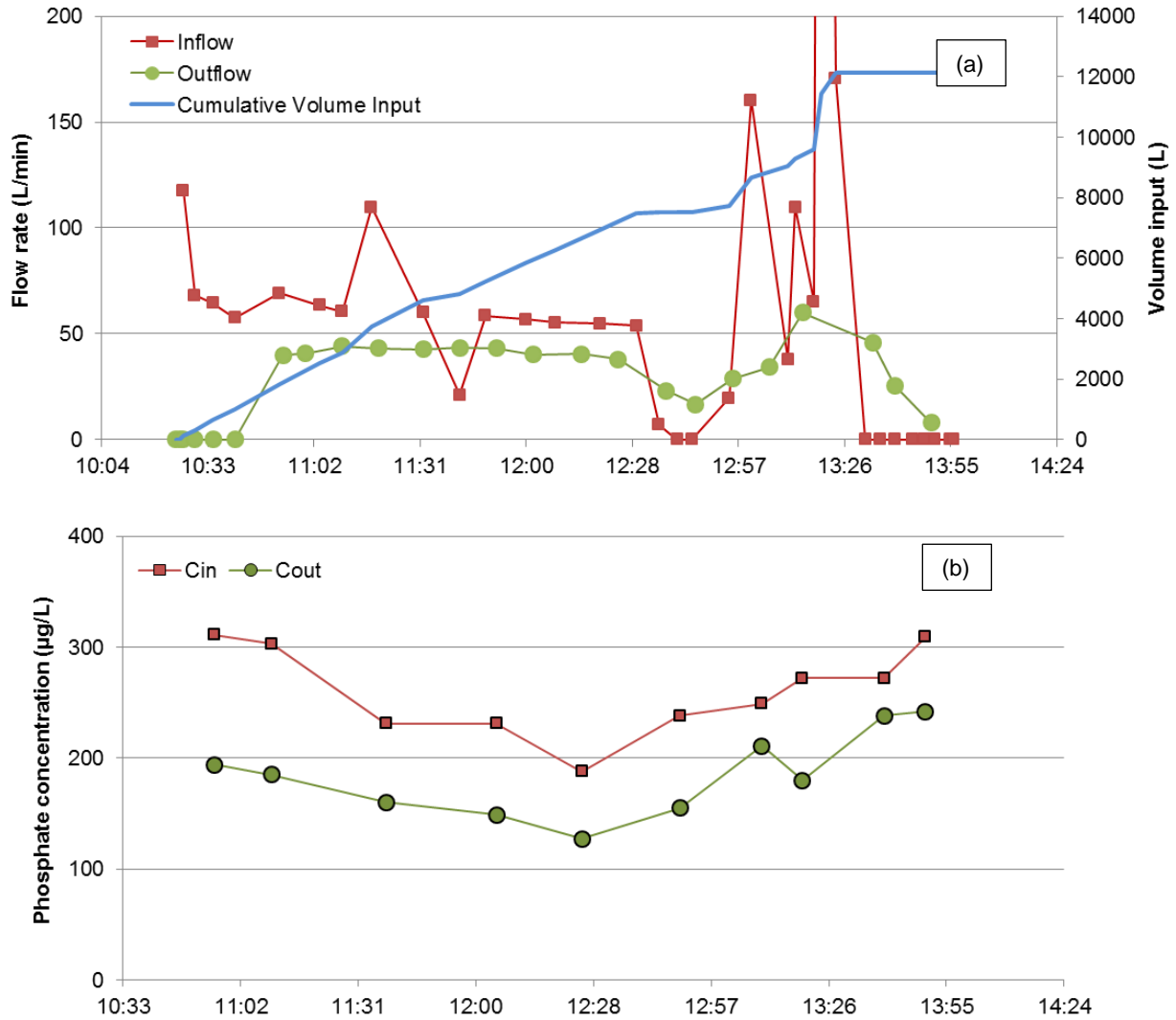
The water samples collected were transported to the Wet Chemistry Laboratory at SAFL within one hour after the test. Samples were filtered with a 0.45 micron membrane filter and the filtrate analyzed for pollutant concentrations (analytical method is described in Section 3c). Phosphate concentrations were determined in each water sample collected. The individual water samples were combined in the laboratory to obtain a composite sample and the metal concentrations were determined in the composite sample.

#### **4d. Results of Field Testing**

Two water truck tests were conducted after the first installation of the iron-enhanced ditch check. The first test was conducted on 28 October, 2014. About 7571 L (2000 gallons) of chemically-dosed water was input to the swale basin at an average rate of 64 L/min (17 gal/min) for two hours. The average upstream water level at the ditch check was around 19 cm (7.6 inches), until the water supply was stopped. However, water was observed to leak around one of the filter corners. The measured flow through the filter was thus high (33 L/min or 8.7 gal/min). The leakage also affected the net phosphate capture: the average phosphate concentrations in the inflow and outflow were 191  $\mu\text{g/L}$  and 153  $\mu\text{g/L}$ , respectively (data not shown). The 19% average phosphate reduction was because water was only partially treated.

The leaking corner in the filter frame was sealed with silicone before the second test on 30 October, 2014. The swale basin was pre-saturated one hour before the test was started (~3785 L or 1000 gallons was input, all of which infiltrated into the soil). In the second test, a total of 12,113 L (3200 gallons) of dosed water was input over three hours. The average flow rate was 64 L/min (17 gal/min) in first two hours, and then the flow rate was set higher (211 L/min average) to increase the upstream water level from 23 cm (9 inches) to the top of the ditch check (~36 cm or 14 inches). The cumulative input volume and flow rates are shown in Figure 21a. The silicone seal was able to partially control the leakage; the average outflow measured was 39 L/min (10 gal/min) at a higher upstream head, which is lower when compared to conditions in the first test. The phosphate removal efficiency of the ditch check also improved; the input phosphate concentrations were decreased (Figure 21b), for an average mass removal of 31% for the test duration.

Due to the leakage issues encountered, the metal concentrations were not determined in the water samples.



**Figure 21. Field testing conducted at the Roseville ditch check on 30 October, 2014: (a) Measured flow rates and input volume (inflow at 13:20 is out of the scale range); and (b) Measured sample phosphate concentrations (Cin and Cout denote concentration in the inflow and filter outflow).**

The filter media assembly was fully re-installed in July 2015 to eliminate the leakage issue. As described earlier, the sand-iron media was placed as one geotextile bag in the frame enclosure. Three water truck tests were conducted on the new ditch check in July and August 2015. No leakage was apparent during these tests and the measured filter outflow rates were much lower than those recorded in the 2014 tests, which confirmed that the re-installation was successful.

The retention performance of the ditch check was tested for three scenarios: (i) low upstream head (15 cm or 6 inches) and low input pollutant concentration ( $\sim 110 \mu\text{g/L}$ ) (test 1); (ii) high upstream head (23 cm or 9 inches) and high input pollutant concentration ( $\sim 320 \mu\text{g/L}$ ) (test 2);

and (iii) low head and high input pollutant concentration (test 3). In each test, approximately 7949 L (2100 gallons) of dosed water was input to the swale basin for about 2.5 to 3 hours. Based on the water volume balance, about 60% of the input water was estimated to have infiltrated into the swale basin and the underdrain. Results of the three field tests are shown in Figure 22.

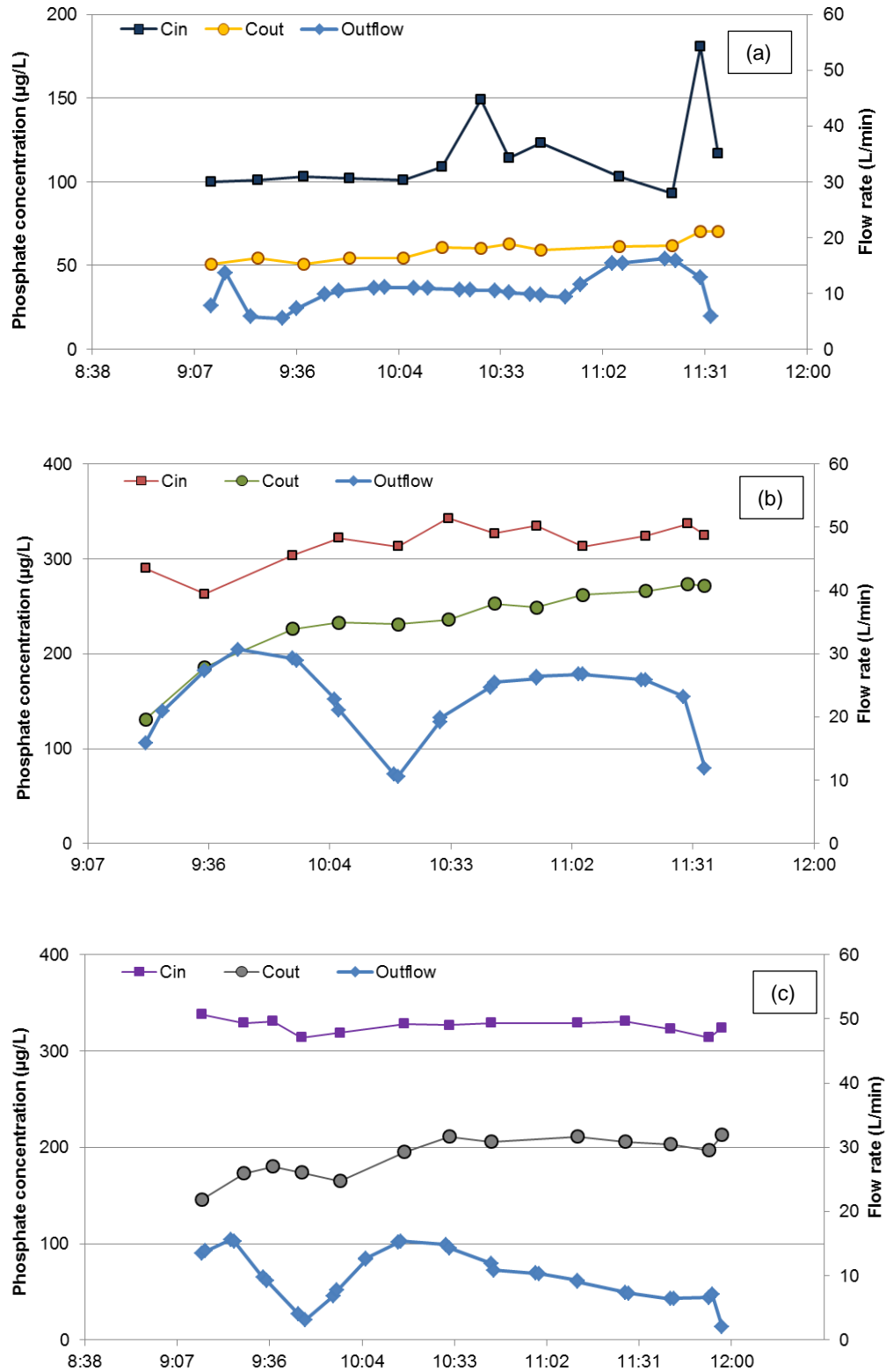
In the first test, the influent phosphate concentrations steadily decreased by 61 to 33% throughout the test (Figure 22a). The measured average flow rate through the filter was 11 L/min (2.9 gal/min), and the mean and median phosphate concentration reductions were 47% and 46%, respectively. About 50% of the total phosphate mass input was retained by the ditch check.

In the second test, conducted at higher upstream head, the flow rate through the filter increased to 24 L/min (6.2 gal/min). About 55 to 16% reduction of the inflow phosphate concentration (316  $\mu\text{g/L}$  average) was observed (Figure 22b). The mean and median reductions were both 26% for this test. The lower removal efficiency can be attributed to the shorter time available for the influent phosphate to interact with the filtration media.

The third field test showed that when water containing high phosphate (326  $\mu\text{g/L}$  average) passed through the filter at a lower flow rate (10 L/min), the retention of phosphates increased (Figure 22c). The decrease in input concentration was between 57 and 34% (mean = 41%; median = 38%), and the overall phosphate mass reduction was 42%. The increased removal efficiency observed in the third test is because of the increased treatment time.

One observation common to all three tests was that the phosphate reduction through the ditch check gradually decreased over the course of the test. It is possible that the phosphate-sorption capacity of the wetted filter media is reduced as the cumulative mass of phosphate retained increases during the test. The ditch check media is rejuvenated by the formation of iron oxide that create new adsorption sites as the filter media dries. This results in improved pollutant retention in the initial stages of the next flow period.

Performance of the ditch check in retaining dissolved metals was determined for the first field test conducted in July 24, 2015. The mean metal concentration in the influent was 25  $\mu\text{g/L}$  Zn and 1.3  $\mu\text{g/L}$  Pb. The effluent contained 21  $\mu\text{g/L}$  Zn and 1.4  $\mu\text{g/L}$  Pb. The ditch check retained about 14% of the zinc load input, but lead was not removed. The low metal retention capability was observed at the MnDOT monitoring site as well. It is possible that the adsorption of metals requires a longer contact time with the filter media (when compared to phosphate), and thus results in low overall removal.



**Figure 22. Results of field testing conducted at the re-installed Roseville ditch check in summer 2015: (a) Test 1 on July 24; (b) Test 2 on August 7; and (c) Test 3 on August 14, 2015. Cin and Cout denote concentration in the inflow and filter outflow.**

## 5. Example Application

An example application of iron-enhanced ditch checks in series will help illustrate how these stormwater control measures (SCMs) can help reduce dissolved concentrations in runoff. We will make the following assumptions:

- Five iron-enhanced ditch checks in series,
- Equal lengths between the ditch checks,
- Equal inflow off of the slope of the ditch into the ditch center, and
- No infiltration in the center of the ditch (this assumption could be approximated by a high groundwater table or a clay-lined drainage ditch).
- A 35% retention in each ditch check for both phosphate and dissolved metals.

Then, the concentration coming out of the last ditch check is given as:

$$C_N = \sum_{i=1}^N (1 - \eta)^i \frac{C_{in}}{N} \quad (11)$$

where  $C_N$  is the concentration of pollutant leaving ditch check  $N$ ,  $\eta$  is the retention efficiency, and  $C_{in}$  is the inflow from the sides of the ditch. For the five ditch-check example, the concentration of dissolved pollutant leaving the fifth ditch check is 33% of the value that enters the ditch.

## 6. Summary and Conclusions

The full-scale design of iron-enhanced swale ditch checks for treating phosphates and dissolved metals was developed through a series of laboratory tests. The type and composition of the filter media were determined by conducting laboratory column experiments and simultaneous modeling exercises. The final composition of the iron-enhanced media was 93% sand and 7% iron shavings (by weight). The design components including filter configuration and installation guidelines were developed after several iterations to accommodate site conditions and monitoring needs at the swales. The iron-enhanced ditch check designs were developed for MnDOT swales and City of Roseville swales. The iron-enhanced media installed in the Roseville swale contained 92.5% sand and 7.5% iron shavings.

Two iron-enhanced ditch checks were constructed in the MnDOT swales located along TH5, Stillwater, in Fall 2014. Shortly after construction, synthetic runoff tests were conducted to determine the ditch check performance. An existing ditch check (soil berm without iron-enhanced media) in the MnDOT swales was also tested for comparison with the new iron-enhanced ditch checks. The iron-enhanced ditch check provided average reductions of 78% for phosphate and 11% for dissolved metals in the field tests conducted using synthetic runoff. As expected, the existing ditch check (soil berm) provided a low phosphate removal of 11% but possessed very good metal retention capacity (78%), both owing to the presence of organic matter in the soil.

Performance of the second iron-enhanced ditch check could not be determined due to water pooling issues at the ditch check berm, where the downstream water levels were equal or higher than the upstream water levels at the ditch check. The possible reasons for the unusual flow routing are incorrect ditch slope, leakage in filter, and/or backward flow on upstream side. The issue was confirmed during two storm events in 2015 as well, and thus this site was not monitored. The existing slope at the site may have to be corrected to properly route the water leaving the ditch check. If the cause of the problem is at the filter bag arrangement, which is allowing seepage and short-circuiting of water, the ditch check may have to be reconstructed. It is recommended that the single-bag design, adopted at the other iron-enhanced ditch check (site 2), be implemented during reconstruction of the ditch check. The single-bag design will eliminate the possibility of leakage between multiple bag layers. As already experienced during construction, the single-bag design utilizes less labor, material, and time when compared to the multiple, filter-sock installation.

The two MnDOT swale sites (iron-enhanced and existing ditch checks) were monitored during storm events from May 2015 through August 2015. For the 17 events sampled for water quality, the iron-enhanced ditch check reduced 15-54% of the phosphate mass load received (mean = 33%, median = 37%). Phosphate mass export occurred during two large storm events (-8.7% and -11% removal), most likely due to very short contact time and/or short-circuiting of inflow. The cumulative phosphate mass removal was 35% for the 17 events. The phosphate mass reductions were better for the small and medium rainfall events. At higher flow volumes, the performance was mixed since both positive and negative mass reductions were observed. The phosphate removals during storm events were lower than for field testing due to variable runoff volume and pollutant loading during storm events.

Metals were generally not reduced by the iron-enhanced section of the ditch check. Increases in effluent metal *EMCs* were observed for a majority of the events, resulting in negative mass reductions for copper, zinc, and lead. Cadmium mass loads were reduced for several events. The phosphate reductions were high (78%) and zinc reduction low (11%) during the water truck tests conducted at this ditch check. The increase in effluent metal concentrations suggests leaching of metals from the filter media itself, and possible additions from the metal frame installed around the filter. The ditch check filter media is relatively new and the metal leaching from filter media may decrease over time; however metals may continue to wash off from the frame which may or may not be significant. The contribution of metals from the two sources may influence the overall metal treatment performance of the iron-enhanced ditch check.

The existing ditch check (that contained no iron-enhanced filter media) did not reduce the runoff phosphate mass loads during 11 out of the 13 events monitored. Effluent *EMCs* were higher than the influent *EMCs*, resulting in net negative reductions of phosphate mass during 11 events. Reduction of metal mass loads was mixed. While zinc and cadmium mass reductions were generally positive (mean = 36% for Zn), positive reductions of lead and copper

occurred for fewer events. Field testing at the existing ditch check showed reductions of 11% for phosphate and 78% for zinc. The higher metal removal efficiency of the un-modified ditch check should be due to the organic matter in the soil berm, which negatively affects phosphate removals. The MnDOT check dam design, if an iron-enhanced filter section were placed in the middle of the ditch check, would incorporate the best of each result, where the current check dam design has a positive retention of metals and the iron-enhanced section has a positive retention of phosphate.

One iron-enhanced ditch check was installed in a swale at Roseville in Fall 2014, and tested using synthetic runoff from a water truck. The two field tests conducted showed average phosphate reductions of 19% and 31%, respectively. Only partial treatment was achieved due to by-passing of influent water around the ditch check assembly. This ditch check was re-installed in Summer 2015 and the leakage was fully fixed. Three field tests were conducted with different flow and pollutant load input condition. For the low upstream head tests, the ditch check decreased the influent phosphate by 47% on average when the input mass load was low, and 43% average when the input phosphate mass was high. In the third test conducted at high upstream head and high mass input, the average phosphate reduction was 26%. The average zinc removal was 14% for the low-head conditions. These observations indicate that the contact time of influent phosphate with the filter media impacts the treatment efficiency of the ditch check.

The field tests and field monitoring have shown that the iron-enhanced inserts into ditch checks have potential to capture phosphate. The treatment efficiency for dissolved metals is generally low. The existing ditch checks (that have not been designed with iron-enhanced media) perform poorly for phosphate removal, but have a better ability to adsorb the metals in runoff. The combination could serve to retain both dissolved metals and phosphate.

Given the monitoring duration of this project, the longevity of the iron-enhanced ditch checks could not be evaluated. While the predicted life expectancy of the iron shavings is approximately 30 years, replacement of the iron-sand filter media every 3-5 years has been recommended for the iron-enhanced sand filter installations (Erickson et al. 2012). Further field monitoring and evaluation is needed to assess the long-term performance of the iron-enhanced swale ditch checks in treating the dissolved pollutants in stormwater runoff. Long-term monitoring will also help determine the maintenance requirements for the iron-enhanced ditch checks.

## **7. Products**

- a) Detailed description, including illustrating photographs, of the design and installation of the iron-enhanced ditch checks for the MnDOT and City of Roseville swales have been provided in Appendix A, and throughout this document.



- b) The typical design recommendations for iron-enhanced swale ditch checks are provided in Appendix B.
- c) All rainfall, flow, and water quality monitoring data collected at the iron-enhanced ditch check site and existing ditch check site in the MnDOT swales have been provided in Appendix D (also in Table 4 to Table 7 in main report). The field testing data collected at the Roseville iron-enhanced swale are provided in Appendix D. The EQUIS project establishment and location establishment forms are placed in Appendix D. The monitoring data will be submitted online in the EQUIS database system.
- d) An article on the iron-enhanced swales ditch checks was published in the July issue of the UPDATES email newsletter (Natarajan and Gulliver, 2015) and at the website <<http://stormwater.safl.umn.edu/>>.

## 8. Public Outreach and Education

Public outreach and education was one of the objectives of this research project. Through this project, partnerships have been established with the MnDOT and City of Roseville. The iron-enhanced ditch checks were designed and constructed as part of roadway projects of these agencies. Several meetings and field visits were held with the engineering staff from MnDOT (5/21/13, 8/20/13, 8/26/13, 4/8/14, 5/8/14, 5/15/14 are some of the meeting dates) and City of Roseville (5/21/13, 7/8/14, 8/14/14, 8/26/14 are some of the meeting dates) to discuss the design and construction requirements at the project sites and to ensure that the project objectives were met.

The concept of iron-enhanced sand filtration (IESF) technology, also known as the “Minnesota filter”, and its phosphate retention abilities have been disseminated to stormwater practitioners in a number of technical presentations. The new application of the IESF technology in ditch checks for swales and ditches has been introduced in some of these presentations. An article about iron-enhanced swale ditch checks, including preliminary findings of this project, has been shared with the public entities through UPDATES, an email stormwater newsletter (Natarajan and Gulliver, 2015) and posted at the website <<http://stormwater.safl.umn.edu/>>. The UPDATES newsletter has currently over 2400 subscribers. Following the completion of the grant project, the results will be written up for publication in a peer-reviewed journal and will be presented at technical conferences and workshops. Additionally, results obtained from this research project will be integrated into the graduate coursework at the University of Minnesota.

## 9. Long-term Results

### 9a. Lessons Learned and Recommendations

- a) The design of iron-enhanced ditch checks involved several laboratory testing, re-designing and re-testing. The iterative design and testing exercises were necessary to ensure that the

- proposed design features were suitable for the swale location, practical for construction and future maintenance, and that monitoring could be performed for research purposes.
- b) Iron-enhanced ditch checks have the ability to decrease the phosphate mass loads from stormwater runoff. On average, about 35% phosphate mass reduction can be expected. For flow volumes from smaller and medium storm events, phosphate reduction can be achieved consistently. Mixed removal efficiency may be exhibited during larger events that contribute high flow volumes and pollutant loads in short duration.
  - c) The dissolved metal treatment efficiency of the iron-enhanced insert into ditch checks was found to be low in this study. Negative mass load removals and increased effluent metal *EMCs* were largely observed during the storm events. The hypothesis is that the sand-iron filter media is acting as a source of metals with possible contributions from the metal enclosure installed around the filter media. If the metal leaching decreases over time, some improvement in the overall metal removal efficiency may be possible.
  - d) Field testing using synthetic runoff showed high phosphate removal and low metal removal at the iron-enhanced ditch check.
  - e) Ditch checks without the iron-enhanced sand filter insert have poor phosphate retention capabilities. The ditch check monitored in this study provided no phosphate removal, but was able to lower the metal concentrations in runoff, especially zinc and cadmium. The organic matter in top soil is favorable for metal retention, as observed in the field testing and field monitoring conducted in this study. This means that ditch checks with the iron-enhanced insert will likely retain both phosphate and the dissolved metals considered herein.
  - f) Further evaluation is needed to determine the longevity of the iron-enhanced ditch checks.
  - g) It is important to ensure proper installation of the iron-enhanced ditch check. Leakage in the filter assembly, especially around the corners and underneath the filter bottom, will affect the effectiveness of the ditch check and result in low pollutant removals.
  - h) It is recommended that filter media containing 93% sand and 7% iron (by weight) be used for the ditch check. When feasible, the filter media shall be installed as one filter log (i.e. one geotextile bag) to prevent possibility of water leakage in between two bags in a multiple-filter log assembly. The single filter log design considerably reduces geotextile material and construction effort, time, and cost.
  - i) A list of design recommendations for typical iron-enhanced swale ditch checks is provided in Appendix B.

## **9b. Partnerships and Alliances**

This 319 project involved partnerships between the Minnesota Department of Transportation (MnDOT), the City of Roseville, and the St. Anthony Falls Laboratory (SAFL), University of Minnesota. Throughout this project, discussions were held to ensure the ditch checks constructed for the roadway projects of MnDOT and City of Roseville met their requirements, and periodic communication on project progress was maintained. It is anticipated that the new

application of iron-enhanced ditch checks developed in this project would be implemented in other swales and ditches under the right-of-way of these agencies. There are no specific plans to continue monitoring without additional funding.

### **9c. Dissemination of Project Results**

The ‘Work Plan Review’ and ‘Public Outreach and Education’ sections provide information on the methods and steps undertaken to disseminate of the results of this research project. The results will be written up for publication in a peer-reviewed journal and will be presented at technical conferences and workshops following the project completion. The information obtained from this project will be of interest to stormwater engineers and managers, watershed planners, and municipal engineers. It is expected that the results of this project will encourage application of the iron-enhanced ditch checks in existing swales and ditches for advanced treatment of stormwater runoff in Minnesota and beyond.

### **III.Final Expenditures**

The final expenditures report for this project has been provided in a separate spreadsheet. The individual objectives and tasks, as outlined in the project work plan, have been listed in the budget spreadsheet document submitted.

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## Appendix A

### 1. Design and Construction of Iron-Enhanced Ditch Checks in MnDOT Swales, TH5, Stillwater

#### 1a. Material Specifications

The specifications of the materials utilized in the iron-enhanced ditch checks constructed in the MnDOT swales are summarized in Table A- 1.

**Table A- 1. Material specifications for the MnDOT iron-enhanced ditch checks (derived from MnDOT ditch check design plans).**

Material	Specifications	Remarks
Class I rip rap	3601	
CA-15 aggregate	3137; 7.6 cm (3 inch) size	
Topsoil borrow special I	60% ASTM C33 Sand, 30% Topsoil, 10% Compost (by volume)	Maximum clay content = 5%. Applied at Site 2.
Topsoil borrow special II	60% ASTM C33 Sand, 30% Topsoil, 10% Peat moss (by volume)	Maximum clay content = 5%. Applied at Site 1.
MN filter mix	93% Sand, 7% Iron shavings (by weight)	Specifications of sand and iron are provided in Table A-2.
Filter bags	15 cm (6-inch) diameter, 0.91 m (3 ft) long	Geotextile fabric specifications are provided in Table A-3. The filter bags were sewn by a third-party vendor.
Filter cage system	PVC coated chain link fencing and steel sign post system	
Sod	Erosion control sod protection; salt resistant	
Drain tile system	10 cm (4 inch) diameter, PVC	3 m (10 ft) long consisting of 1.5 m (5 ft) porous section and 1.5 m solid section.
Monitoring well	10 cm (4 inch) diameter, porous PVC pipe	

**Table A- 2. Specifications of iron and sand used in the MnDOT ditch check filter (data provided by the manufacturer/distributor).**

U.S. Sieve Size (Opening size)	% Passing	
	Iron A	Sand
4 (4.75 mm)	100%	100
8 (2.36 mm)	95-100%	81
16 (1.18 mm)	75-90%	49
30 (0.6 mm)	25-45%	20
50 (0.3 mm)	0-10%	4
100 (0.15 mm)	0-5%	1
200 (0.075 mm)		0.5

**Table A- 3. Specifications of geotextile fabric WINFAB 2300 (Data source: <www.winfabusa.com>)**

PROPERTY	TEST METHOD	MARV English	MARV Metric
Grab Tensile	ASTM D-4632	400 x 335 lbs	1780 x 1491 N
Grab Tensile Elongation	ASTM D-4632	20% x 15%	20% x 15%
Trapezoidal Tear Strength	ASTM D-4533	145 x 125 lbs	645 x 556 N
CBR Puncture	ASTM D-6241	1250 lbs	5563 N
Wide Width Tensile	ASTM D-4595	2760 x 2700 lbs/ft	40.3 x 39.4 kN/m
UV Resistance (500 hrs)	ASTM D-4355	90%	90%
Percent Open Area	COE-02215	8%	8%
Apparent Opening Size (AOS)*	ASTM D-4751	30 US Std. Sieve	0.60 mm
Permittivity	ASTM D-4491	1.5 sec <sup>-1</sup>	1.5 sec <sup>-1</sup>
Permeability	ASTM D-4491	.13 cm/sec	.13 cm/sec
Water Flow Rate	ASTM D-4491	115 gpm/ft <sup>2</sup>	4685 lpm/m <sup>2</sup>

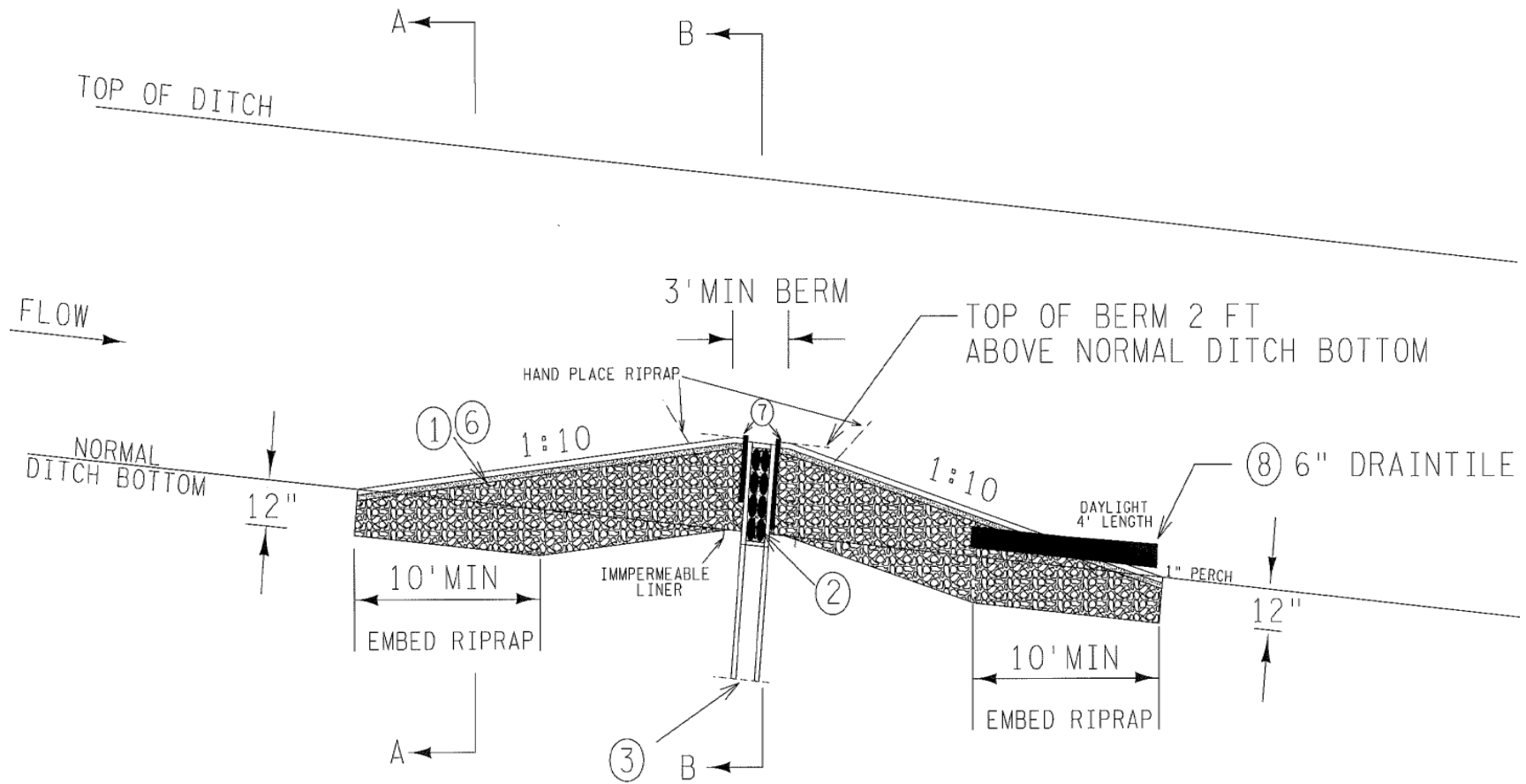
\*Maximum Average Roll Valve

## 1b. Ditch Check Design Plans

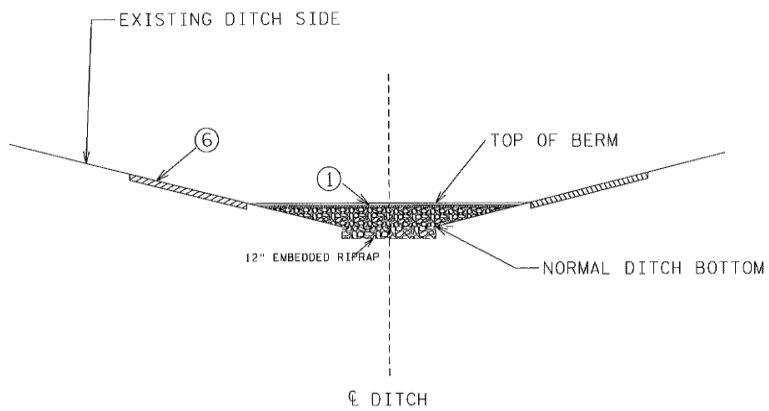
The design plans of the iron-enhanced ditch checks constructed at Site 1 of the MnDOT swales in Stillwater are provided in Figure A- 1. The design plans were obtained from the Water Resources Division of MnDOT, and are not the as-built plans. As described in the main report, the second iron-enhanced ditch check utilized a single filter media log. Because of this modification, a single MN filter log is applicable in place of the multiple filter bags shown in the engineering drawings provided.



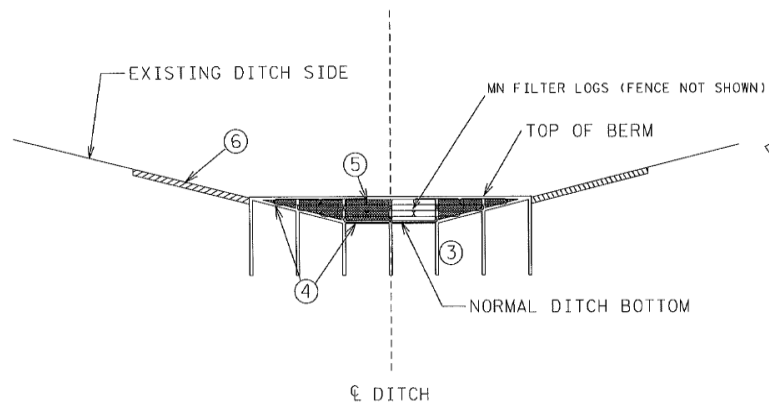
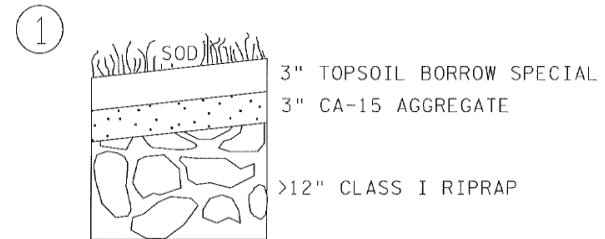
# PROFILE VIEW



\*\*PLANS ARE NOT DRAWN TO SCALE\*\*

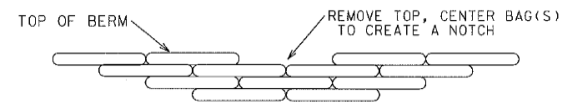


SECTION A-A

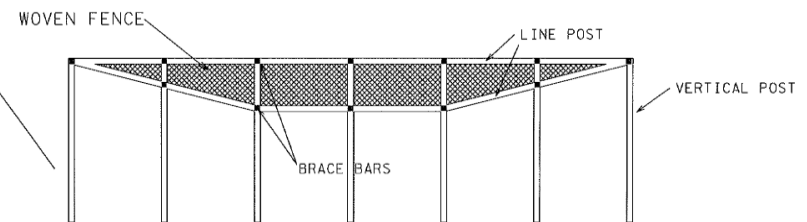


SECTION B-B  
FILTER CAGE CROSS-SECTION

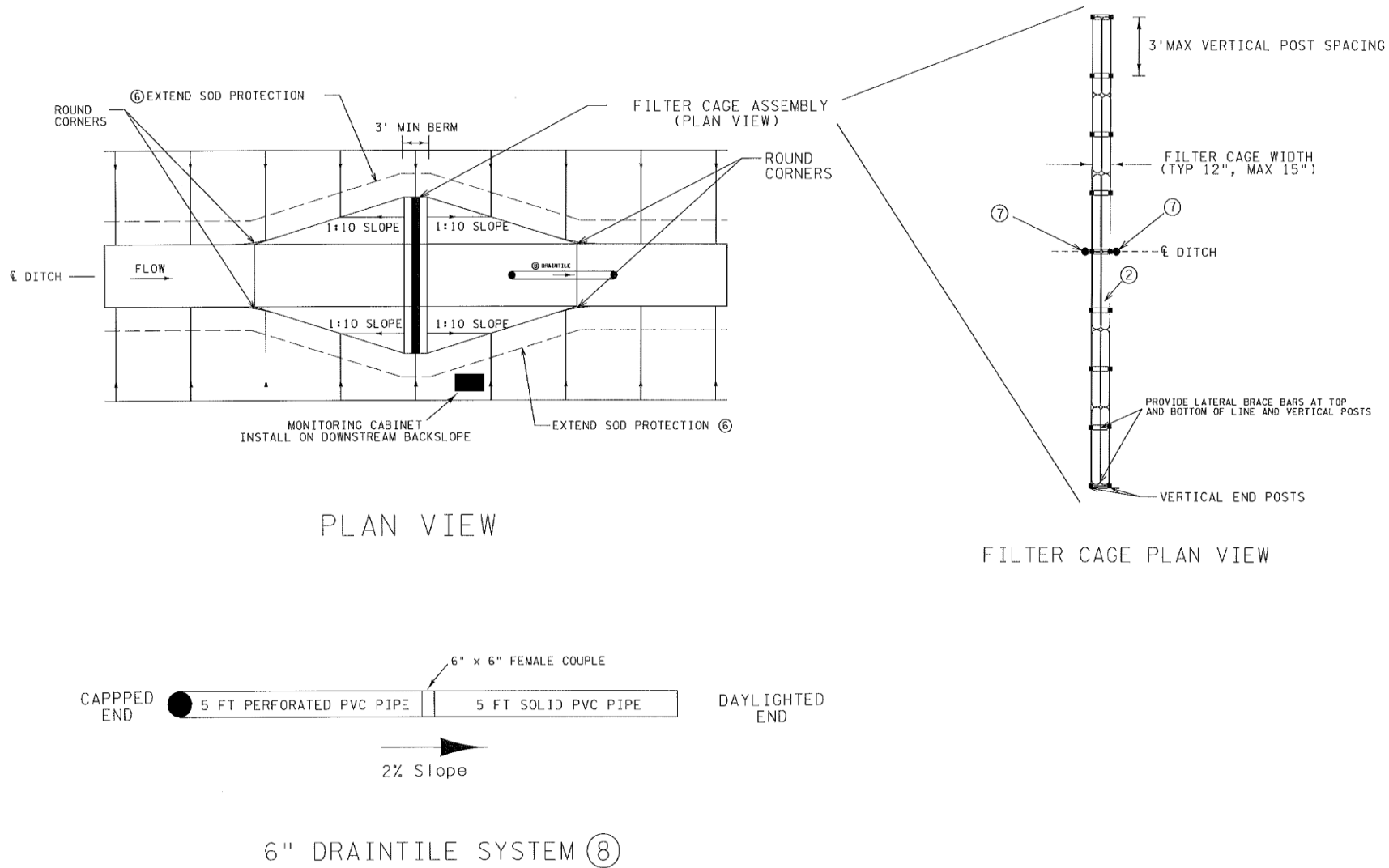
FILTER BAG STACKING PATTERN



CAGE ASSEMBLY (FRONT AND REAR FACE)



\*\*\*PLANS ARE NOT DRAWN TO SCALE\*\*\*



\*\*PLANS ARE NOT DRAWN TO SCALE\*\*

**Figure A- 1.** Engineering drawings of the iron-enhanced ditch check design for the swales at TH5, Stillwater (Courtesy: MnDOT).

### 1c. Description of Iron-Enhanced Ditch Check Construction at MnDOT Swales (Sites 1 and 2)

Two iron-enhanced ditch checks were constructed in the MnDOT swales in Stillwater during September 15 to 26, 2014. The installation procedure is described and illustrated using photographs taken at the time of construction.

The existing ditch checks were dug out completely at site 1 and site 2 at the MnDOT swales along TH5, Stillwater. A trench was dug (sub-cut) below the normal grade (trench width = 0.5 m (18 inch); depth ranged from 10 cm (4 inch) at middle to 30 cm (12 inch) at sides) across the ditch cross-section (i.e. perpendicular to the direction of flow). The sub-cut, lined with an impermeable liner, was provided to place the first layer of filter bags just below the normal ditch bottom for preventing flow seeping below the filter. A filter cage was built around the trench to contain the filter bags; PVC-coated chain link fencing was tied around vertical sign posts that were braced at the top, bottom, and laterally to form the filter cage assembly (Figure A- 2). The bottom of the sign post conformed to the ditch side slope and bottom, and the top of the post was cut to be at least 7.6 cm (3 inch) below the finished grade.







**Figure A- 2. (a) Construction stage showing the filter cage enclosure. (b) Completed filter cage enclosure at ditch check site 1.**

The filter media mix, consisting of 93% sand and 7% iron shavings (iron A), (by weight), was purchased from a MnDOT-approved vendor in MN. The filter mix was filled into filter bags measuring 15 cm (6 inch) diameter, and 0.9 m (3 ft) in length. The filter bags were used to build the ditch check at site 1, as proposed during the design development. Each filter bag was equipped with drawstrings for closure, and two handles for carrying the bags easily during installation and future maintenance. A zip-tie closure was also added to seal the bags well.

After placing a layer of 5 cm (2 inch) approximate depth of loose filter media in the trench, the first layer of filter bags were placed in two rows, along the entire width of the trench (transverse to the flow direction). The space between the filter bags, corners, and top of the bag layer were filled with loose media before placing the next layer of bags (Figure A- 3a). The process was repeated until the filter cage was filled with the filter bags (Figure A- 3b). The open spaces in the cage were filled with loose media throughout the installation. The final filter size in the direction of flow was approximately 0.4 m (17 inch). The bags tended to flatten when stacked.









**Figure A- 3. (a) Construction stage showing the placement of filter bags and filling media within the filter cage enclosure. (b) Completed filter installation at ditch check site 1.**

At ditch check site 2, a modified version of the filter was installed. Instead of using individual filter bags to build the filter (as described for site 1), a single bag was used. A sheet of geotextile fabric was placed covering the inside of the entire filter cage (i.e. lining the fencing from inside). The sand-iron mix was filled into this geotextile wrap, until the entire cage was full (Figure A- 4a). The overhanging geotextile sheet was then folded over on the top and sealed by zip-ties all around, thereby wrapping the filter media into a large, single bag. One layer of filter bags used in site 1 was placed over the wrap bag to finish the filter installation (Figure A- 4b). The filter width (in the direction of flow) was approximately 0.4 m (17 inch).







**Figure A- 4. (a) Construction stage showing placement of filter media into a single wrap-bag; (b) Completed filter at ditch check site 2, MnDOT swales.**

Once the filter assembly installation was completed, Class I riprap was placed at a 1:10 slope on either side of the filter cage to build the berm (thickness of riprap > 31 cm (12 inches)). The riprap was covered with 8 cm (3 inch) CA-15 aggregate base (Figure A- 4b, Figure A- 5). The gaps between riprap and filter cage fencing were filled with river rock. The ends of the filter cage were backfilled with bentonite to prevent bypass of water around the filter.

During this construction stage, a drain tile system was included on the downstream end of the ditch checks to route water draining through the filter (Figure A- 5). The 10 cm (4 inch) diameter, 3 m (10 ft) long PVC pipe (where, 1.5 m (5 ft) of perforated pipe was coupled to 1.5 m of solid pipe) was installed at the normal ditch slope such that it was perched at least 2.5 cm (1 inch) from the bottom and the last 1.2 m (4 ft) was day-lighted. Monitoring wells were included in the ditch check design as part of the monitoring plans for these sites. The 10 cm diameter PVC monitoring wells installed in the lowest point of the ditch check (along the

centerline) on the upstream and downstream faces of the ditch check. The monitoring wells were tied to the filter cage fencing post before the placement of Class I riprap during construction (Figure A- 3).



**Figure A- 5. Construction stage showing the rip rap and river rock layers placed around the filter cage, and drain tile on the downstream side at ditch check site 1, MnDOT swales.**

A 8 cm (3 inch) thick layer of special topsoil mix was used to cover the aggregate base. The top soil borrow special consisted of 60% C-33 sand, 30% topsoil, 10% peat moss (by volume) at Site 1 (Figure A- 6), and 60% C-33 sand, 30% topsoil, 10% compost (by volume) at Site 2. Erosion control sod protection (salt-resistant sod) was laid over the top soil layer (Figure A- 7, Figure A- 8). The sod was watered periodically after construction, before field monitoring was started (Figure A- 8).





**Figure A- 6. Construction stage showing placement of top soil mix at ditch check site 1, MnDOT swales.**



**Figure A- 7. Construction stage showing placement of sod at ditch check site 1, MnDOT swales.**



**Figure A- 8. Iron-enhanced ditch check constructed at site 2, MnDOT swales.**

## 2. Design and Construction of Iron-Enhanced Ditch Checks in City of Roseville Swales

### 2a. Material Specifications

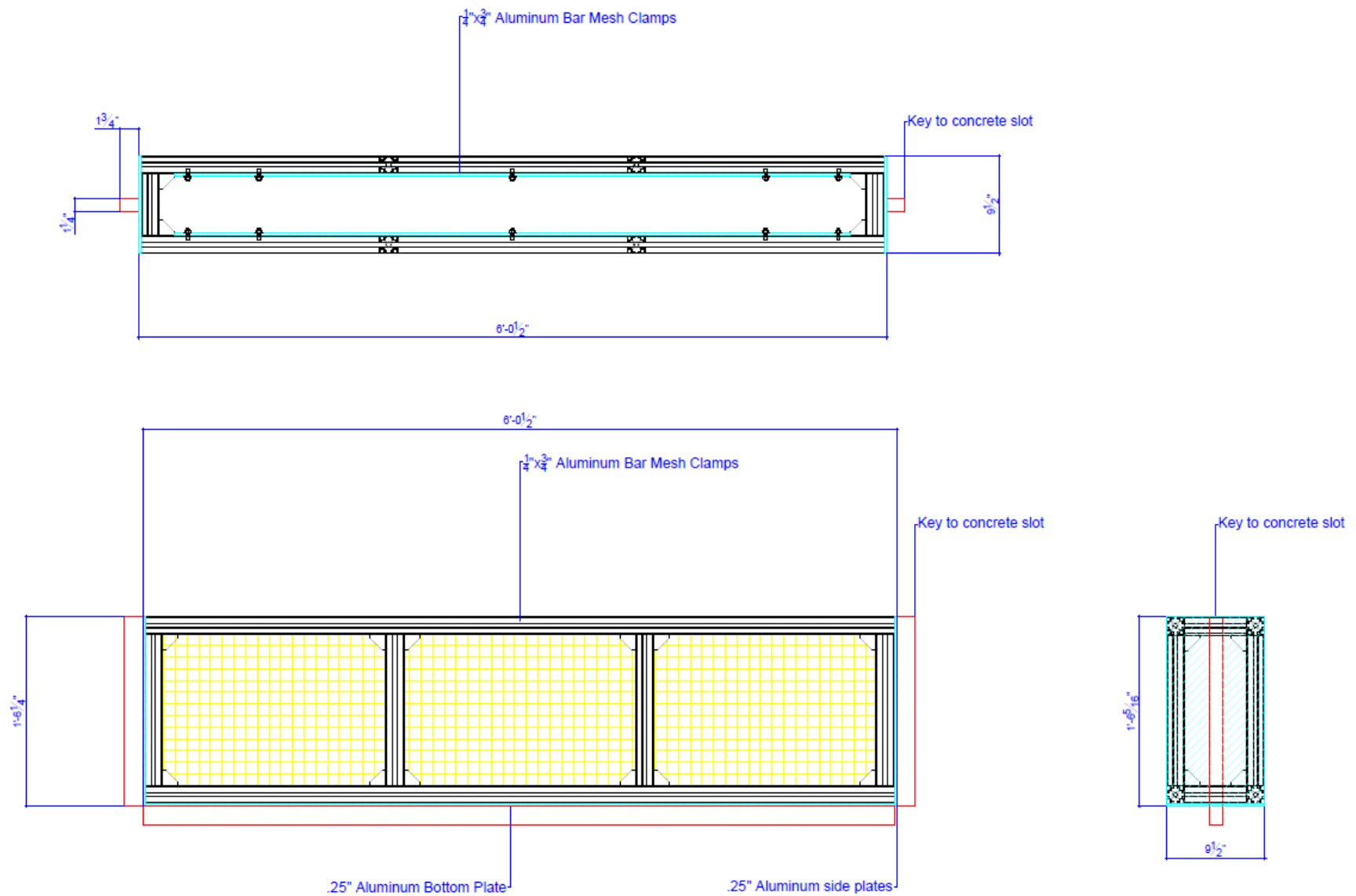
Specifications of the sand and iron shavings used in the filter media of the ditch check are provided in Table A- 4. Specifications of the geotextile fabric used for the filter bags and outer filter wrap are provided in Table A- 3. It must be noted that only a single geotextile bag was used in the re-installed ditch check.

**Table A- 4. Specifications of sand and iron used in the ditch check filter media at Roseville (data were provided by the manufacturer/distributor).**

U.S. Sieve Size (Opening size)	% Passing	
	Iron B	Sand
4 (4.75 mm)	100%	100
8 (2.36 mm)	90-100%	81
16 (1.18 mm)	40-70%	49
30 (0.6 mm)	0-10%	20
50 (0.3 mm)	0-5%	4
100 (0.15 mm)		1
200 (0.075 mm)		0.5

A filter frame enclosure for the filter media bags was designed and constructed at SAFL. Specifications and drawings of the aluminum frame enclosure are provided in Figure A- 9, and photograph of the frame is shown in Figure A- 12. The frame was made from Bosch Rexroth aluminum framing. T-slot mesh (1 in. opening) was affixed to the face of the frame (i.e. upstream and downstream sides in the direction of flow). Aluminum plates (6 mm or 0.25 in.) formed the sides and bottom of the frame. A 6 mm-thick aluminum plate was attached to the sides and bottom to serve as a key for fitting the frame into the notch in the concrete wall.





**Figure A- 9. Drawings of the aluminum filter enclosure designed at SAFL for the Roseville ditch check.**

## 2b. Description of Ditch Check Construction at Roseville Swales

As mentioned in the main report, the Roseville ditch check was first installed in September 2014, and re-installed in July 2015 to fix an issue with the previous installation. In the first installation, multiple filter media bags were used. In the second installation, the filter media was placed inside a single geotextile bag inside the frame enclosure. The descriptions of both the old and new ditch check at the Roseville swale basin are provided. It must be noted that the old filter media, removed from the individual filter bags, was utilized in the re-installed ditch check.

For the first installation in September 2014, filter bags were made from woven geotextile fabric. Two sets of 7.6 cm (3 inch)-diameter filter bags were made: one set was 0.61 m (2 ft) long, and the second was 0.91 m (3 ft) long. Different lengths were chosen to achieve overlap of filter material. The filter bags had two carrying handles to ease handling during installation and future maintenance.

Sand and iron shavings (iron B) were purchased, and the sand-iron filter mix prepared at SAFL. Weighed quantities of sand and iron were mixed at a proportion of 92.5% sand and 7.5% iron (by weight) in a mortar mixer (Figure A- 10). The mixer was run for at least 20 minutes to achieve uniform mixing of the sand and iron.



**Figure A- 10. Mixing of sand and iron shavings in a mortar mix.**



The sand-iron mix was filled into the filter bags using a funnel setup. The funnel setup was constructed by attaching an orange traffic cone to a wooden frame; the cone was cut at the bottom to have an opening large enough for free-fall of the filter mix. The funnel setup was held up from the ground with a forklift and the sand-iron mix poured into the bag via the funnel with a hand shovel (Figure A- 11). As the bag was being filled, it was tapped periodically to ensure there were no gaps in the fill (therefore compaction was achieved by gravity). Once full, a small piece of the filter fabric was placed inside the bag and the drawstrings tied up to seal the bag.



**Figure A- 11. Filling filter media mix into the filter socks using the funnel setup at SAFL.**

The ditch check was installed by the project personnel from University of Minnesota. The existing steel weir was removed from the concrete wall with the help of the City of Roseville Maintenance division personnel. After clearing the debris in the concrete area, the aluminum frame enclosure was inserted into the concrete wall (Figure A- 12). The sides and bottom of

the enclosure were made water-tight by applying a silicone-based sealant, and the sealant was allowed to completely dry for one day.



**Figure A- 12. Aluminum frame enclosure affixed in the concrete wall at the Roseville swale site.**

Next, the filter media bags were installed. A geotextile bag (sized to the inner dimensions of the enclosure) was placed inside the enclosure. A layer of loose filter mix was placed inside the bag, and then two rows of filter bags were placed (Figure A- 13). The first row consisted of three, 0.61 m (2 ft) long bags and the second consisted of two, 0.91 m (3 ft) bags. The gaps between the bags and their sides were filled with loose filter media and the next layer of filter bags placed. The process of filling gaps and placing filter bags was repeated until the top of the frame. The bag lengths were also alternated between 0.61 m and 0.91 m in successive rows. Once the enclosure was full, the top of the geotextile wrap fabric was folded over and sealed to complete the filter assembly, as shown in Figure A- 14.





**Figure A- 13. Installation of filter socks within the frame enclosure at Roseville swales (first iron-enhanced ditch check installed in October 2014).**



**Figure A- 14. Photograph of the completed Roseville iron-enhanced ditch check filter assembly taken in October 2014.**

The ditch check filter was re-installed in July 2015. All filter bags inside the frame enclosure were removed, opened up, and the filter media poured out into a large container and mixed using a shovel. The frame enclosure was not disturbed. A new geotextile bag, sized to the inner dimensions of the enclosure, was placed inside the enclosure. The old, well-mixed filter media was gradually filled into this bag, and the bag was sealed on the top. The visual appearance and final dimensions of the new filter were same as the old installation (Figure A-15).



**Figure A- 15. Photograph of the re-installed iron-enhanced ditch check filter at Roseville swales site in July 2015.**

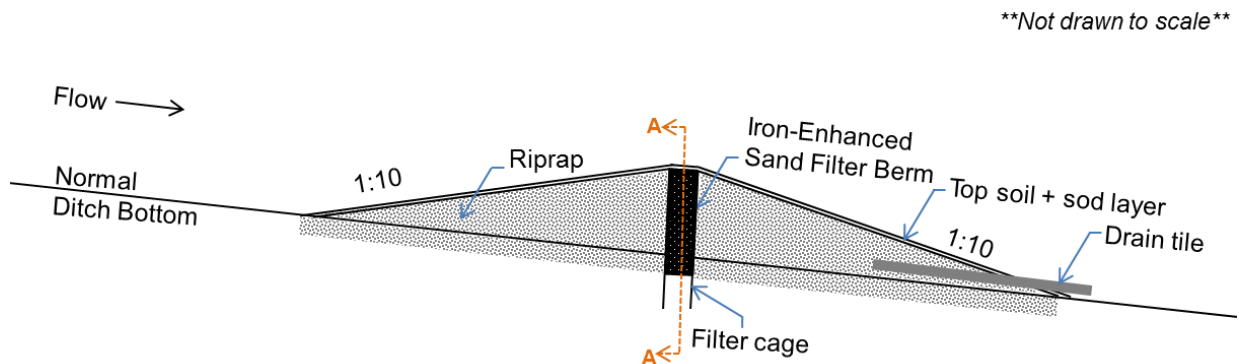


## Appendix B

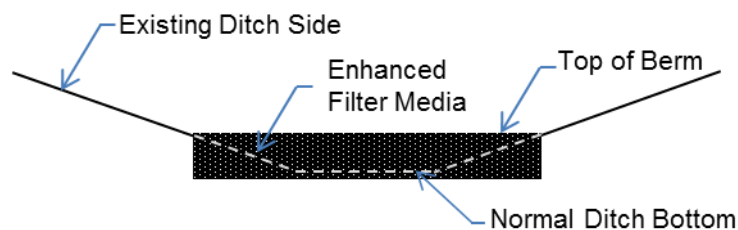
### Typical Design Recommendations for Iron-enhanced Swale Ditch Checks

Based on the ditch check design and construction at the MnDOT swales and the lessons learnt throughout this project, recommendations on the typical design of an iron-enhanced swale ditch checks have been developed for application in future installations. A schematic of the recommended iron-enhanced ditch check design features are illustrated in Figure B- 1.

(a)



(b)



**Figure B- 1. Schematic of recommended design for a typical iron-enhanced swale ditch check. (a) Profile view and (b) Cross-sectional view (Section A-A).**

- a) Sand conforming to the gradation used in this study shall be used in the filter media. The sand should be clean and pre-washed if necessary. Sand type coarser than ASTM C-33 sand may be used.
- b) The iron-enhanced sand filter (IESF) media shall contain 7 to 7.5% iron shavings by weight. Higher iron content is not recommended since iron may clump as it rusts and possibly clog the filter.
- c) The IESF shall be rectangular in cross-section for ease of construction.
- d) The filter berm depth shall be 30 to 43 cm (12 to 17 inches) in the direction of flow.

- e) The filter berm length (perpendicular to flow direction) shall extend across the ditch width, i.e. filter shall be sufficiently long such that runoff does not flow around the filter.
- f) The filter berm height shall be at least 0.46 m (18 inches); however, the sizing shall be determined based on the site conditions.
- g) The filter media shall be filled within a woven geotextile enclosure in the berm. It is recommended that the filter media be installed within a single geotextile enclosure, i.e. as one 'filter log' in the ditch check berm. The single filter log-design is recommended since it utilizes less geotextile material and reduces the overall construction time and effort. The single log-design also reduces the possibility of water seeping between multiple filter logs. If the single filter log design is not feasible for the site conditions, multiple filter logs shall be stacked to build the IESF berm. Two rows of filter logs shall be placed in a staggered pattern to allow good overlap between the bags. A geotextile sheet covering all sides the filter logs (i.e. upstream and downstream faces and sides of the berm) should be installed. Gaps between the outer geotextile cover and filter logs, and gaps between individual filter logs shall be filled with loose IESF media.
- h) The IESF berm must be trenched into the ground to prevent flow-bypass underneath the filter media; i.e. the filter log shall be installed at least 0.15 m (6 inches) below the normal ditch bottom. If multiple filter logs are used, the bottommost filter logs shall be trenched into the ground.
- i) An impermeable liner shall be placed directly underneath the filter log.
- j) A frame shall be constructed around the filter berm to hold the filter log(s) in place. The frame will ease installation of the IESF media and prevent dislocation of the media during high-flow conditions and/or other disturbances by human/natural causes.
- k) The edge of the filter log shall be properly sealed against the ditch side. This can be done by trenching the filter log to the ditch side. Alternatively, any gap present between the filter log and ditch side shall be filled with loose filter media and then the sides backfilled with topsoil or sealed with clay, if necessary. This is important to ensure water does not by-pass the filter log.
- l) Class I riprap shall be placed at 1:10 slope on either side of the filter log to form the check dam.
- m) If exposed aggregate is undesirable, the riprap check dam shall be covered with top soil and sod. As done in this project, the top soil cover shall consist of 60% C-33 sand, 30% topsoil, 10% peat moss (by volume). Compost shall not be used in the top soil mix as it can leach additional phosphorus into the water and reduce the overall effectiveness of the iron-enhanced ditch check.
- n) A porous drain tile shall be added on the downstream side of the ditch check, if necessary, to allow proper drainage of the water.

# Appendix C

## Grant Project Summary

Projec title: Assessing Iron-Enhanced Swales for Pollution Prevention

Organization(Grantee): University of Minnesota

Project start date: 1/1/2011 Project end date: 8/31/2015 Report submittal date: 9/1/2015

Grantee contact name: John S. Gulliver Title: Professor

Address: 2 Third Ave S.E.

City: Minneapolis State: MN Zip: 55414

Phone number: 612-625-4080 Fax: 612-624-4398 E-mail: gulli003@umn.edu

Basin (Red, Minnesota, St. Croix, etc.) / Watershed & 8 digit HUC:: Upper Mississippi/Rice Creek and Valley Branch Watershed Districts County: Ramsey and Washington County

**Project type** (check one):

- ☐ Clean Water Partnership
- ☐ Total Maximum Daily Load (TMDL)/Watershed Restoration or Protection Strategy (WRAPS) Development
- ☐ 319 Implementation
- ☒ 319 Demonstration, Education, Research
- ☐ TMDL/WRAPS Implementation

## Grant Funding

Final grant amount: \$400,000 Final total project costs: \$780,736.91

Matching funds: Final cash: \$ Final in-kind: \$380,736.91 Final Loan: \$

MPCA project manager: Greg Johnson

## For TMDL / WRAPS Development or TMDL / WRAPS Implementation Projects only

Impaired reach name(s):

AUID or DNR Lake ID(s):

Listed pollutant(s):

303(d) List scheduled start date:  Scheduled completion date:

*AUID = Assessment Unit ID*

*DNR = Minnesota Department of Natural Resources*



## **Executive Summary of Project**

### ***Problem***

The treatment of dissolved phosphorus and metals in runoff requires specialized filtration media, which, however, is not accounted for in the typical swale ditch check designs currently employed. In this project, ditch checks with iron-enhanced sand filter insert were developed to increase the retention of phosphate and metals in roadside swales and ditches.

### ***Waterbody Improved***

Iron-enhanced swale ditch checks were designed and installed as part of roadway projects of the Minnesota Department of Transportation (MnDOT) and City of Roseville. The iron-enhanced ditch checks were found to reduce the phosphate mass load in runoff. The effect of the treatment achieved on the water quality of the receiving water bodies was not evaluated in this project.

### ***Project highlights***

The effectiveness of the iron-enhanced ditch checks installed in the MnDOT and Roseville swales was investigated by field testing using synthetic runoff, and field monitoring during natural rainfall events in Fall 2014 and from Spring to Summer 2015. A ditch check containing no enhanced media was also monitored for comparison.

### ***Results***

The MnDOT iron-enhanced ditch check monitored provided consistent phosphate mass reductions during 15 events (33% mean; 37% median). The cumulative mass removal was 35%. Metal reductions were largely negative, possibly due to leaching of metals from the filter media. The Roseville iron-enhanced ditch check exhibited 47%, 43%, 26% phosphate removal and 14% zinc removal under different field testing scenarios. The ditch check without the filter insert showed no phosphate removal but retention of metals in the top soil cover. Since the iron-enhanced ditch check monitoring excluded the effect of top soil, it can be presumed that an iron-enhanced ditch check will retain metals in the soil covering the ditch check and retain phosphate in the filter section. The project results were utilized to develop typical design recommendations for future applications of the iron-enhanced ditch check.

### ***Partnerships***

This 319 project involved partnerships between the Minnesota Department of Transportation (MnDOT), the City of Roseville, and the St. Anthony Falls Laboratory (SAFL), University of Minnesota.

### ***Pictures***



**Iron-enhanced ditch check constructed at MnDOT swales in TH5, Stillwater.**



**Photograph of the iron-enhanced ditch check installed at the City of Roseville swales.**



## Appendix D

### 1. Field Testing Data Summary for Roseville Swale Ditch Check

**Table D- 1. Summary of field testing data collected at the iron-enhanced ditch check installed in the City of Roseville swale basin. (Conversion: 1 L = 0.26 US gallon)**

Data Summary	First Ditch Check		Re-Installed Ditch Check		
	Test 1	Test 2	Test 2	Test 2	Test 3
Date	10/28/2014	10/30/2014	7/24/2015	8/7/2015	8/15/2015
Cumulative Volume Input (L)	8127	12,117	7998	9353	8353
Test duration (hr:min)	2:15	3:30	2:30	2:20	2:50
Average outflow (L/min)	36	38	11	24	10
Influent phosphate ( $\mu\text{g/L}$ )	$191 \pm 39$	$260 \pm 40$	$115 \pm 24$	$316 \pm 22$	$326 \pm 6.9$
Effluent phosphate ( $\mu\text{g/L}$ )	$153 \pm 39$	$184 \pm 38$	$59 \pm 6.3$	$235 \pm 41$	$191 \pm 21$
Phosphate concentration reduction (mean, median) (%)	-0.9 to 42 (19, 20)	13 to 39 (29, 33)	61 to 33 (47, 46)	55 to 16 (26, 26)	57 to 34 (41, 48)
Total phosphate mass reduction (%)	16%	31%	50%	27%	42%
Remarks	Leakage observed	Leakage partially sealed	Filter re-installed, no leakage	Filter re-installed, no leakage	Filter re-installed, no leakage

### 2. Field Monitoring Data Summary for MnDOT Swale Ditch Checks

**Table D- 2. Monitoring data for iron-enhanced ditch check in MnDOT swales in TH5, Stillwater: Part 1**

Event Date	Rainfall depth (cm)	Rainfall duration (hr)	Flow volume (L)	SRP EMC <sub>IN</sub> (µg/L)	SRP EMC <sub>OUT</sub> (µg/L)	Cu EMC <sub>IN</sub> (µg/L)	Cu EMC <sub>OUT</sub> (µg/L)	Pb EMC <sub>IN</sub> (µg/L)	Pb EMC <sub>OUT</sub> (µg/L)	Zn EMC <sub>IN</sub> (µg/L)	Zn EMC <sub>OUT</sub> (µg/L)	Cd EMC <sub>IN</sub> (µg/L)	Cd EMC <sub>OUT</sub> (µg/L)
05/03/15	1.13	7.92	2687	666	352	23.1	33.6	0.528	2.16	18.6	39.8	0.0763	0.0987
05/10/15	0.91 <sup>†</sup>	n/a	2781	885	504	103	68.0	0.535	1.12	28.0	30.1	0.0953	0.0647
05/14/15	1.14 <sup>†</sup>	n/a	2968	627	401	68.3	62.4	0.942	1.10	16.5	23.1	0.0517	0.0680
05/17/15	1.02 <sup>†</sup>	n/a	3455	561	302	72.4	90.8	1.24	1.97	24.9	59.1	0.2643	0.0517
05/24/15*	3.14 (1.98, 1.15)	20.4, 9.25	8806	1000	461	67.5	72.2	1.12	1.27	13.9	30.3	0.0237	0.0303
05/29/15	1.59	19.3	4424	417	228	80.9	82.3	3.69	6.08	25.3	53.1	0.1397	0.0543
06/03/15	1.90	13.5	4357	280	179	30.1	70.9	0.602	1.30	24.7	26.3	0.0410	0.0403
06/11/15	1.08	10.8	2000	457	328	42.8	69.7	0.516	1.32	77.3	98.6	0.0507	0.0373
06/13/15	1.77	4.75	4804	168	98	71.1	70.6	1.28	1.45	29.5	35.6	0.0257	0.0153
06/17/15*	2.54 (1.32, 1.22)	3.83, 2.67	9013	114	74	38.3	52.4	0.940	1.03	24.8	24.7	0.0173	0.0127
06/22/15	1.24	2.83	3304	128	81	16.9	69.3	0.478	1.55	30.5	33.5	0.0587	0.0400
06/28/15	0.76	1.83	1301	283	241	66.0	71.7	1.43	1.19	24.2	36.1	0.0560	0.0357
06/29/15	1.88	0.75	4211	116	69	9.75	59.6	0.546	1.39	12.7	43.8	0.0270	0.0283
07/06/15*	10.7	12.7	17593	218	241	10.6	9.23	0.490	0.217	15.8	14.3	0.0166	0.0129
07/28/15	0.79	2.17	1501	202	115	10.1	59.3	0.891	1.23	15.6	113	0.0250	0.0247
08/18/15	3.54	27.9	5206	274	175	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	4.11	5.42	7446	184	200	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

<sup>†</sup> Rainfall depth from the nearby weather station.

n/a Data not available.

\*Data combined for two events and represents net performance for two combined sampling events.

**Table D- 3. Monitoring data for iron-enhanced ditch check in MnDOT swales in TH5, Stillwater: Part 2**

Event Date	SRP M <sub>IN</sub> (g)	SRP M <sub>OUT</sub> (g)	SRP M <sub>R</sub> (%)	Cu M <sub>IN</sub> (mg)	Cu M <sub>OUT</sub> (mg)	Cu M <sub>R</sub> (%)	Pb M <sub>IN</sub> (mg)	Pb M <sub>OUT</sub> (mg)	Pb M <sub>R</sub> (%)	Zn M <sub>IN</sub> (mg)	Zn M <sub>OUT</sub> (mg)	Zn M <sub>R</sub> (%)	Cd M <sub>IN</sub> (mg)	Cd M <sub>OUT</sub> (mg)	Cd M <sub>R</sub> (%)
05/03/15	1.20	0.63	47.1	62.2	90.3	-45.2	1.42	5.80	-309	50.1	107	-114	0.205	0.265	-29.3
05/10/15	0.62	0.35	43.1	287	189	34.1	1.49	3.12	-110	77.8	83.7	-7.65	0.265	0.180	32.2
05/14/15	1.37	0.87	36.0	203	185	8.72	2.79	3.27	-17.1	48.9	68.6	-40.3	0.153	0.202	-31.6
05/17/15	1.94	1.04	46.2	250	314	-25.5	4.29	6.80	-58.6	86.0	204	-138	0.913	0.178	80.5
05/24/15*	8.81	4.06	53.9	595	636	-6.91	9.83	11.2	-13.5	123	267	-118	0.208	0.267	-28.2
05/29/15	1.84	1.01	45.3	358	364	-1.71	16.3	26.9	-65.0	112	235	-110	0.618	0.240	61.1
06/03/15	1.22	0.78	36.1	131	309	-136	2.62	5.65	-116	107	115	-6.61	0.179	0.176	1.63
06/11/15	0.91	0.66	28.2	85.6	139	-62.9	1.03	2.64	-156	155	197	-27.6	0.101	0.0747	26.3
06/13/15	0.81	0.47	41.7	341	339	0.68	6.16	6.98	-13.3	142	171	-20.8	0.123	0.0737	40.3
06/17/15*	1.03	0.66	35.4	345	472	-37.0	8.47	9.32	-10.0	224	223	0.39	0.156	0.114	26.9
06/22/15	0.42	0.27	36.6	56.0	229	-309	1.58	5.11	-223	101	111	-9.92	0.194	0.132	31.8
06/28/15	0.37	0.31	14.9	85.9	93.2	-8.53	1.85	1.55	16.5	31.5	47.0	0.00	0.0728	0.0464	36.3
06/29/15	0.49	0.29	40	41.0	251	-511	2.30	5.85	-154	53.3	184	-246	0.114	0.119	-4.94
07/06/15*	3.84	4.24	-10.5	186	162	12.8	8.61	3.81	55.8	279	251	10.0	0.293	0.227	22.3
07/28/15	0.30	0.17	43.1	15.1	89.1	-488	1.34	1.85	-38.2	23.4	169	-624	0.038	0.037	1.33
08/18/15	1.42	0.91	36.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	1.37	1.49	-8.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

\* Data represents net performance for two combined sampling events.

**Table D- 4. Monitoring data for existing un-modified ditch check in MnDOT swales in TH5, Stillwater: Part 1**

Event Date	Rainfall depth (cm)	Rainfall duration (hr)	Flow volume (L)	Phosphate EMC <sub>IN</sub> (µg/L)	Phosphate EMC <sub>OUT</sub> (µg/L)	Cu EMC <sub>IN</sub> (µg/L)	Cu EMC <sub>OUT</sub> (µg/L)	Pb EMC <sub>IN</sub> (µg/L)	Pb EMC <sub>OUT</sub> (µg/L)	Zn EMC <sub>IN</sub> (µg/L)	Zn EMC <sub>OUT</sub> (µg/L)	Cd EMC <sub>IN</sub> (µg/L)	Cd EMC <sub>OUT</sub> (µg/L)
05/14/15	1.14 <sup>†</sup>	n/a	1429	486	631	19.9	28.6	1.90	1.13	43.2	25.8	0.0777	0.0590
05/29/15	1.59	19.3	1000	290	292	19.9	12.4	3.91	3.86	66.9	111	0.0403	0.0303
06/03/15	1.90	13.5	2906	342	370	9.49	9.49	0.95	0.470	17.64	8.01	0.0223	0.0157
06/07/15	2.13 <sup>†</sup>	n/a	9884	143	428	5.75	9.36	0.38	0.315	7.32	5.99	0.0140	0.0260
06/13/15	1.77	4.75	12641	232	195	39.1	24.7	1.34	0.611	15.8	10.1	0.0263	0.0247
06/20/15	1.22	2.67	1650	57.2	160	6.30	11.6	0.479	0.603	25.4	22.0	0.0387	0.0270
06/22/15	1.24	2.83	4807	144	301	55.9	14.3	0.798	1.32	18.1	15.0	0.0367	0.0477
06/29/15	1.88	0.75	7230	181	176	4.80	7.30	0.360	0.784	8.62	5.13	0.0067	0.0137
07/06/15*	10.7	12.7	25181	416	357	52.0	33.5	1.18	0.754	105	25.0	0.0629	0.0111
07/12/15	6.25	8.08	9022	121	166	4.13	6.43	0.224	0.429	4.37	5.31	0.0160	0.0383
07/18/15	2.36	2.08	2004	169	151	8.99	49.6	0.380	1.095	44.2	4.47	0.0113	0.0113
08/18/15	3.54	27.8	600	38	79	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	4.11	5.42	9773	244	380	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

<sup>†</sup> Rainfall depth from the nearby weather station.

n/a Data not available.

\* Data represents net performance for two combined sampling events.



**Table D- 5. Monitoring data for existing un-modified ditch check in MnDOT swales in TH5, Stillwater: Part 2**

Event Date	SRP M <sub>IN</sub> (g)	SRP M <sub>OUT</sub> (g)	SRP M <sub>R</sub> (%)	Cu M <sub>IN</sub> (mg)	Cu M <sub>OUT</sub> (mg)	Cu M <sub>R</sub> (%)	Pb M <sub>IN</sub> (mg)	Pb M <sub>OUT</sub> (mg)	Pb M <sub>R</sub> (%)	Zn M <sub>IN</sub> (mg)	Zn M <sub>OUT</sub> (mg)	Zn M <sub>R</sub> (%)	Cd M <sub>IN</sub> (mg)	Cd M <sub>OUT</sub> (mg)	Cd M <sub>R</sub> (%)
05/14/15	0.69	0.90	-29.8	28.5	40.8	-43	2.72	1.62	40.5	61.8	36.9	40.3	0.111	0.084	24.0
05/29/15	0.29	0.29	-0.7	19.9	12.4	38	3.91	3.86	1.28	66.9	111	-65.5	0.040	0.030	24.8
06/03/15	0.99	1.08	-8	27.6	27.6	0.0	2.77	1.37	50.8	51.3	23.3	54.6	0.065	0.046	29.9
06/07/15	1.41	4	-199	56.9	92.5	-63	3.78	3.11	17.6	72.3	59.2	18.2	0.138	0.257	-85.7
06/13/15	2.93	2.46	16	495	312	37	17.0	7.73	54.4	199	128	35.8	0.333	0.312	6.3
06/20/15	0.09	0.26	-180	10.4	19.1	-83	0.79	1.00	-26.0	41.9	36.3	13.4	0.064	0.045	30.2
06/22/15	0.69	1.44	-109	269	68.7	74	3.83	6.37	-66.1	86.9	72.1	17.1	0.176	0.229	-30.0
06/29/15	1.30	1.27	2	34.7	52.7	-52	2.60	5.67	-118	62.3	37.1	40.4	0.048	0.099	-105
07/06/15*	10.49	8.99	14	1310	843	36	29.6	19.0	35.8	2632	630	76.1	1.583	0.278	82.4
07/12/15	1.09	1.50	-37	37.3	58.0	-55	2.02	3.87	-91.8	39.5	47.9	-21.3	0.144	0.346	-140
07/18/15	0.34	0.30	11	18.0	99.42	-452	0.761	2.19	-188	88.6	8.95	89.9	0.023	0.023	0.0
08/18/15	0.02	0.05	-111	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
08/22/15	2.39	3.71	-55	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

\* Data represents net performance for two combined sampling events.

n/a Data not available

The EQUIS Project Establishment form and Location Establishment form submitted to the MPCA are attached.



**Minnesota Pollution  
Control Agency**

520 Lafayette Road North  
St. Paul, MN 55155-4194

# Project Establishment Form

EQuIS Database  
Metadata Forms

Doc Type: STORET/EQuIS Project Establishment

**Bold = required entry**

**Monitoring year:** 2015 **Today's date** (mm/dd/yyyy): 9/10/2015

## Project Information

**Project name:** Assessing Iron-Enhanced Swales for Pollution Prevention  
*Example: Pelican River Watershed District Clean Water Partnership (EQuIS/WSD)*

**Project ID:** PRJ0 7854  
*Example: PRJ01234 If unknown, contact EQuIS team member. (EQuIS/WSD)*

**Swift contract number:** 36547  
*Enter if applicable.*

**Project is** (check one): ☒ New ☐ Updated

**Project purpose:** ☐ Protection ☐ Restoration ☒ Both  
(WSD)

**Monitoring type** (check one): ☐ Condition ☒ Effectiveness ☐ Problem investigation  
(WSD)

**Project type** (check one):  
☒ 319 ☐ Watershed Restoration and Protection (WRAP) ☐ Surface Water Assessment Grant (SWAG)  
☐ Clean Water Partnership (CWP) ☐ Volunteer project ☐ Special project ☐ WRAP  
☐ Other (explain): \_\_\_\_\_  
(WSD)

**Start date** (mm/dd/yyyy): 1/1/2011 **End date** (mm/dd/yyyy): 8/31/2015  
*Example: 06/01/2015 (EQuIS/WSD) Example: 06/01/2017 (EQuIS)*

Does this project submit the same data to Minnesota Pollution Control Agency (MPCA) another way? ☐ Yes ☒ No

If so, how? \_\_\_\_\_  
*Example: Citizen Lake Monitoring Program*

**Lead organization name:** University of Minnesota

**Local project coordinator** (project manager): John S. Gulliver

Organization: University of Minnesota

Address: 2 Third Ave S.E.

City: Minneapolis State: MN Zip: 55414

Phone: 612-625-4080 E-mail: gulli003@umn.edu

**MPCA project manager:** Greg Johnson  
(WSD)

**Laboratory Name(s)** (List all)

Saint Anthony Falls Laboratory, University of Minnesota

Analytical Geochemistry Laboratory, University of Minnesota

(Please fill out the front and back of this form.)

## Field Procedure Information (Provide a monitoring plan with standard operating procedures in electronic form if possible.)

**Sample collection method(s):** Automated sample collection with ISCO 6700 water samplers

*Example: grab with weighted bucket*

**Transparency tube type (stream sampling only):** ☐ T-tube ☐ Secchi tube

### Field measurements – methods and instrumentation:

Water level (upstream and downstream head at enhanced ditch check) and water level over weir (at un-modified ditch check) with pressure transducers; rainfall depth with tipping bucket rain gauge (model EZ200)

*Example: pH, spec. cond., temp., and DO with Hydrolab; transparency with t-tube*

Instrumentation Northwest, Inc. pressure transducer models PS9105 (head at ditch check) and PS9805 (weir level)

Probe - make and model: PS9805 (weir level)

Field turbidimeter or probe make and model (if different from above):

### Flow method (stream sampling only):

**Stage method (if applicable):** ☐ Tape-down distance ☐ Wire-weight ☐ Relative water level, tape-down method

☐ Automated stage recorder ☐ Other (please describe):

**Gage method (if applicable):** ☐ Staff ☐ USGS

☐ Other (please describe):

## Locations to be Visited (Enter field information for stream or lake)

Field name or Lake name (ex. Site 1 or Lake Harriet)	Location ID (ex. S005-545 or 27-0016-00-101)	Location description (ex. Str.wtr. inlet to Crow R, New London, MN)
Iron-enhanced ditch check in TH5 swale_Upstream side (TH5 IESF Ditch Check-Influent)	SS00060	Iron-enhanced ditch check installed in a swale along MN-5 E (45.0186, 92.8586) in Stillwater, MN. Influent sampling was done on upstream side of this ditch check filter.
Iron-enhanced ditch check in TH5 swale_Downstream side (TH5 IESF Ditch Check-Effluent)	SS00062	Iron-enhanced ditch check installed in a swale along MN-5 E (45.0188, 92.8586) in Stillwater, MN. Effluent sampling was done on downstream side of this ditch check filter.
Un-modified ditch check in TH5 swale_Upstream side (TH5 Unmodified ditch check-Influent)	SS00061	Un-modified ditch check (with no filter media) located in a swale along MN-5 E (45.0244, 92.8563) in Stillwater, MN. Influent sampling was done on upstream side of this ditch check.
Un-modified ditch check in TH5 swale_Downstream side (TH5 Unmodified ditch check-Effluent)	SS00063	Un-modified ditch check (with no filter media) located in a swale along MN-5 E (45.0250, 92.8563) in Stillwater, MN. Effluent sampling was done on downstream side of this ditch check.

## Documentation

EQuIS contact: Nancy Flandrick

Date established (mm/dd/yyyy): 9/16/2015

(WSD)



## Location Establishment Form

**EQulS Database**  
Metadata Forms

Doc Type: STORE/EQulS Location Establishment

**Bold font = Required entry**

Monitoring year: 2015  
Today's date: 9/10/2015  
Program: 319  
Project ID: Surface Water PRJ07854  
Example: PRJ01234

Project or facility name: Assessing Iron-Enhanced Swales for Pollution Prevention  
Example: Big Lake CWP or Anoka Regional Landfill

### Location Information

MPCA Use Only Location ID	MPCA Use Only Co-located	Waterbody type	AUID	Location description	Field ID/code	State	County	Latitude (DecDeg or UTM)	Longitude (DecDeg or UTM)	Geopositioning method	Geopositioning datum	GPS carrier brand/ model	Map scale	HUC code	Township/Section/Range
		Storm Sewer		An iron-enhanced ditch check was constructed in the swales along MN-5 East, in Stillwater, MN. The ditch check is in the swale along MN-5 E between McDonald Dr N and 53 rd St N. From MN-36 E, take exit to MN-5 W/Stillwater Blvd N, turn right onto MN-5 W, go 1.4 miles, then turn left onto McDonald Dr N. From the intersection of McDonald Dr N and MN-5 E, walk 500 ft to the enhanced ditch check. Influent sampling was done on upstream side of this ditch check.	TH5 IESF Ditch Check-Influent	MN	Washington	45.018646	92.85866	...type in other	Google Maps				T 029 N R 20 E or W S 07
		Storm Sewer		An iron-enhanced ditch check was constructed in the swales along MN-5 East, in Stillwater, MN. The ditch check is in the swale along MN-5 E between McDonald Dr N and 53 rd St N. From MN-36 E, take exit to MN-5 W/Stillwater Blvd N, turn right onto MN-5 W, go 1.4 miles, then turn left onto McDonald Dr N. From the intersection of McDonald Dr N and MN-5 E, walk 500 ft to the enhanced ditch check. Effluent sampling was done on downstream side of this ditch check.	TH5 IESF Ditch Check-Effluent	MN	Washington	45.018788	92.85866	...type in other	Google Maps				T 029 N R 20 E or W S 07
		Storm Sewer		The existing un-modified ditch check (without enhanced filter media) is located in the swale along MN-5 E, in Stillwater, MN. The ditch check is in the swale located along MN-5 E, between 53rd St N and 58 St N. From MN-36 E, take exit to MN-5 W/Stillwater Blvd N, turn right onto MN-5 W, go 1.4 miles, then make U-turn at McDonald Dr N, go 0.6 miles to 53rd St N. From the intersection of 53rd St N and MN-5 E, walk 200 ft to the un-modified ditch check. Influent sampling was done on upstream side of this ditch check.	TH5 Unmodified Ditch Check - Influent	MN	Washington	45.0244	92.85635	...type in other	Google Maps				T 029 N R 20 E or W S 06
		Storm Sewer		The existing un-modified ditch check (without enhanced filter media) is located in the swale along MN-5 E, in Stillwater, MN. The ditch check is in the swale located along MN-5 E, between 53rd St N and 58 St N. From MN-36 E, take exit to MN-5 W/Stillwater Blvd N, turn right onto MN-5 W, go 1.4 miles, then make U-turn at McDonald Dr N, go 0.6 miles to 53rd St N. From the intersection of 53rd St N and MN-5 E, walk 200 ft to the un-modified ditch check. Effluent sampling was done on downstream side of this ditch check.	TH5 Unmodified Ditch Check-Effluent	MN	Washington	45.025	92.85635	...type in other	Google Maps				T 029 N R 20 E or W S 06
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Note: Add rows to include more stations.

### Documentation (MPCA Use Only)

Local and/or MPCA project manager requesting location establishment  
EQulS team member responsible for location establishment  
Date(s) established in EQulS